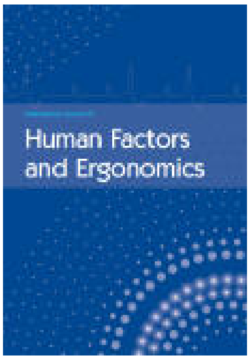

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Operator perspectives and attitudes to evolving tasks and tools in power grid operations

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Abstract: Due to increasingly volatile, distributed generation, the electric power system is undergoing significant change with increasing automation and altered operator roles. This study explores grid operators' own perspectives on how their tasks and tools are evolving in response to these changes. Emotional responses play a key role in technology acceptance and influence safety, performance and sensemaking, which are critical aspects of safe and reliable control room systems. Therefore, this study examined operator attitudes using an exploratory questionnaire study targeting Nordic grid operators. The results (N = 15) indicated that the increasingly volatile power system requires more active balancing work and that automation is seen as essential. However, concerns about reliability, stress and skill requirements were raised; these were influenced by past experiences of tool overload and outdated systems contributing to hesitation. Well-calibrated trust in automation is vital for safe implementation and thus organisations need to keep up with technological and operational change.

Keywords: electric power system; control room operator role; automation; attitudes.

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1 Introduction

With the increase of intermittent, distributed energy production, the electric power system is becoming less plannable and more complex. This, in turn, affects both the grid structure and grid operations in transmission system operator (TSO) organisations (European Commission, 2023; International Energy Agency, 2023). TSO organisations are responsible for overseeing the high-voltage electricity grid within specific geographic areas, ensuring secure, reliable and efficient operation. This oversight is conducted from control rooms, which operate as open systems interacting with their environment. At these locations, interdependent technological, human and organisational subsystems interact with one another and with external conditions to transform inputs into outputs (Hendrick and Kleiner, 2001; Pasmore et al., 1982). This configuration aligns with established definitions of socio-technical systems as open systems composed of interacting social and technical elements (Ropohl, 1999).

As the power grid changes, a transformation of control room dynamics is inevitable, necessitating systems that support both human and technological capabilities. How operators themselves understand the tasks associated with their new operator role is therefore important (Svensson et al., 2024). This shift highlights the significance of understanding how operators adapt to evolving tasks and tools in an increasingly automated environment. From a socio-technical point of view, operator roles and tasks are also affected when technology changes. As a result, greater attention is directed towards automated grid operations systems, a fact that is substantially reshaping operator roles (Endsley and Connors, 2017; Prostejovsky et al., 2019; Stevens-Adams et al., 2015).

Even in highly automated grid operations, operators remain essential for handling disturbances, unexpected events and ambiguous situations. Their effectiveness depends not only on technical competence but also on how they understand their responsibilities and how much they trust the tools that support their work. When responsibilities are unclear or when trust in automation is poorly calibrated, system reliability can be compromised. When operators lack a clear understanding of their role, their responsibilities and the intended division of labour between human and automated agents, several risks can arise. Ambiguity about one's role can reduce situational awareness, delay decision-making (Weick, 1995) and impair trust calibration (Lee and See, 2004), all of which can directly influence both system reliability and operator wellbeing. These risks highlight the fact that performance in complex control environments is not only a technical issue but also depends on how operators make sense of their shifting responsibilities and new tools.

One concept that helps explain these interpretive processes is sensemaking. Sensemaking describes how people interpret and create meaning around situations that are novel, ambiguous or unexpected (Klein et al., 2006; Weick, 1995). According to organisational sensemaking (Weick, 1995), this process begins with personal identity: how people understand their own expertise, autonomy and place within an organisation. Thus, grid operators' interpretations of new tools and shifting responsibilities are shaped not only by technical factors but also by how these changes align or conflict with their sense of who they are as professionals. These identity considerations play a central role in the development of trust towards automation and future tools. Emotional responses play a key role in technology acceptance and contribute significantly to both safety and performance (Lee and See, 2004; Merritt et al., 2013). In general, people tend to rely on the automation they trust and reject the automation they do not. Therefore, trust should be calibrated to the capabilities of the automated system (Lee and See, 2004). Over-trust can lead to automation complacency, where operators monitor the system less critically and are slower to detect errors or unexpected behaviour. This over-reliance reduces situational awareness and can undermine safety, making it essential that operators remain critical towards automated outputs (Bahner et al., 2008; Onnasch et al., 2014; Wickens et al., 2015). Trust is further shaped by cultural factors and is therefore influenced by the shared long-term experiences of a group (Riley, 1996; Zuboff, 1988). This is particularly relevant in grid operations, for which teamwork and collective experience influence how new tools are interpreted and integrated into daily work.

While previous studies have examined the future grid operator role (for example, a review by Prostejovsky et al., 2019; and an ACTA interview study by Stevens-Adams et al., 2015), they have not focused on empirical accounts of operators' own experiences of role changes and less is known about operators' attitudes towards their current and emerging tasks and tools. Given the rapid technological developments in power system operations, it is increasingly important to understand how today's operators perceive and make sense of the tools that will shape their future work. Such insights are critical for designing safe and effective control room systems: if operators experience new tools as confusing or unreliable, they may override automation prematurely, rely on it excessively, react too slowly or misinterpret system conditions. Moreover, organisational changes are more likely to succeed when operators accept and identify with them. Thus, in an increasingly automated grid environment, understanding these attitudes plays a central role in supporting reliable system performance. To address these gaps, the purpose of this study was to explore grid operators' own perspectives on how their tasks and tools are evolving in response to advancements within the power system. The study sought to deepen the understanding of operator attitudes, as emotional responses can play a critical role in technology acceptance and influence safety, performance and sensemaking. Specifically, the study investigated:

- How operator tasks have changed over the past five years
- How the tasks are expected to continue developing
- Operators' attitudes towards existing tools, as well as those incorporating higher degrees of automation
- How operators perceive that new tools affect their tasks.

An exploratory questionnaire study design was used to address the gaps described in operator attitudes towards task changes in an increasingly automated environment. The exploratory nature of the study design is reflected in the fact that, rather than statistically validating hypotheses, it focused on investigating how grid operators' tasks have changed, how they are expected to change in the future, operators' attitudes towards existing support tools and how new tools and automation affect their tasks.

1.1 Contributions and relevance for practice

The results of this study are relevant for TSO organisations, as they illustrate how control room operators perceive the influence of increasing automation on their work tasks, trust in systems and competence. The findings suggest that technological change may need to be accompanied by organisational responses related to work design, training and support structures. The results are also relevant for control room operators themselves, as they reflect commonly reported concerns and experiences regarding changing task demands, tools and competence requirements in highly automated power system operations. More broadly, this study contributes to human factors and human–automation interaction research by providing empirical, questionnaire-based insights into the human and organisational aspects of automation in safety-critical power system contexts. The results were further discussed using existing theoretical concepts on automation, trust and operator identity and open suggestions for further investigations within the area of sensemaking and role changes within future control room operations.

2 Background

Electric grid control rooms rely on teams of human operators with defined roles to ensure a continuous and secure electricity supply, to operate and maintain the infrastructure and to restore service after outages. Their work spans several operational sets of tasks. Grid operators balance supply and demand, reconfigure the network through switching and assess transmission capacity to keep the power system stable and secure. They also perform security analysis to ensure resilience under contingencies, manage voltage and protection systems, coordinate cross-border flows and lead restoration efforts. These different activities are divided between operators and carried out to maintain the system in what is considered normal operation, within which all technical constraints are achieved, reserve margins are adequate and a stable balance exists between electricity demand and generation. In this state, equipment operates within its limits and potential disturbances can be handled without requiring exceptional measures. If any of the conditions during normal operations are no longer fulfilled and the system can no longer be operated within its security margins, it transitions into disturbed operation (Prostejovsky et al., 2019).

With the extensive deployment of renewable energy sources and the advent of various new technologies, the grid now exhibits quicker and more complex dynamics. One response is the transition to a shorter trading and settlement period, intended to better handle variability in weather-dependent generation (Svenska Kraftnät, 2024a). A trading period is the time slot in which electricity is bought and sold. A shorter trading period means the time slots are smaller, so the market can react more quickly when electricity production or demand changes. Also, the control room introduces higher levels of automation into the balancing process, including the move towards automated activation in the manual frequency restoration reserve (mFRR), which supports more efficient system balancing and alignment with European requirements. With the automation of mFRR, the system can automatically activate reserves (in other words, backup power for stabilising the grid) when needed to balance the electricity grid, as opposed to being done via telephone as previously (Nordic Balancing Model, 2025; Svenska Kraftnät, 2025). In parallel, a new method called flow-based capacity calculation is being introduced to improve the determination of available transmission capacity in power grids. It uses a mathematical model to simulate and assess feasible electricity flows in advance, instead of traditional rule-of-thumb approaches. This transition is mandated by EU law and affects all market participants (Hamon and Ravi, 2023; Svenska Kraftnät, 2024b).

3 Method

An exploratory questionnaire was used to collect data, focusing on current and anticipated tasks and tools used by grid operators in Nordic TSO organisations. This approach was identified as an appropriate data-collection method because operators hold first-hand insights into their own work practices. Due to the limited accessibility of this specialist group, a questionnaire was considered a feasible choice.

3.1 Participants

A digital questionnaire was distributed to TSO organisations at the beginning of 2025 via contacts in the TSO domain. One contact at each of the contacted TSO organisations was e-mailed with a description of the study and asked to distribute the questionnaire to operators in their respective organisations. This sampling strategy (a form of snowball sampling) was appropriate, given the difficulty of accessing individuals with specific expertise in the TSO domain. However, snowball sampling can introduce selection bias and may limit the representativeness of the sample. Grid operators (N = 15) with varying roles responded anonymously. They were between 30 and 55 years of age, with operator experience ranging from less than four years to more than 24 (Table 1).

Table 1 Respondent ID, role and years of experience

Respondent ID	*Role*	*Years of experience*
R1	Balancing engineer	15–19
R2	Specialist	5–9
R3	Balance operator	5–9
R4	Power system operator	1–4
R5	Switching engineer	20–24
R6	Switching engineer	20–24
R7	Engineer on duty	5–9
R8	Grid supervisor/engineer on duty	20–24
R9	Engineer on duty	More than 24
R10	Engineer on duty	5–9
R11	Engineer on duty	1–4
R12	Grid supervisor	5–9
R13	Switching and disturbance management	20–24
R14	Power system analyst	5–9
R15	Power system analyst	1–4

Table 2 Questionnaire sections and purpose of each

Questionnaire sections		*Purpose*
Section 1	Consent	Consent to analysis of responses
Section 2	Introduction	Gather basic demographic and professional background information
Section 3	Tasks during normal operations	Identify key responsibilities of grid operators during normal operations and explore how these tasks have changed over the past five years and may evolve in the future
Section 4	Tasks during disturbed operations	Identify key responsibilities of grid operators during disturbed operations and explore changes over time and anticipated future developments
Section 5	Support tools	Collect open-ended responses about the support tools used during normal and disturbed operations. A five-point Likert scale was also used to investigate attitudes towards current tools
Section 6	Introduction of new support tools	Investigate attitudes towards new tools and higher levels of automation using a five-point Likert scale, including perceived impact, effectiveness and challenges
Section 7	Final question	Provide space for additional thoughts or insights not covered in previous questions and obtain consent for future contact

3.2 Data collection

The digital questionnaire tool LimeSurvey was used for collecting questionnaire data. The full questionnaire contained 20 items spread across seven sections (Table 2). The complete instrument can be found in Appendix B. Considering the exploratory study design, the questionnaire combined open and closed-ended questions, allowing qualitative insights to be complemented by quantitative, descriptive responses. To support the credibility of the findings, the questionnaire relied primarily on open-ended questions. In line with the exploratory study design, the purpose of the Likert-scale questions was to support the open-ended questions by analysing the responses descriptively.

Table 3 Tasks in Sections 3 and 4 of the questionnaire

Task category	*Description*
Load balancing	Maintain grid stability by matching electricity production with consumption in real-time
Emergency load balancing	Rapidly adjust the balance between electricity production and consumption to stabilise the grid
Frequency control	Monitor and adjust the grid frequency to stay within acceptable limits
Reserve management	Manage and deploy reserve power sources to handle unexpected consumption spikes or production drops
Operational switching	Execute planned switching orders to reconfigure the grid for maintenance or other operational needs, including voltage regulation
Emergency switching	Execute emergency switching operations to reroute power and/or during the restoration phase after major disturbances
Safety switching	Implement safety protocols and switching procedures to ensure safe working conditions for maintenance crews
Overseeing overall operation	Oversee the overall operation of the control room, ensuring overall delivery
reporting	Document and report on the status of the grid, incidents and any actions taken during the shift
IT system monitoring	Continuously monitor IT systems and applications to ensure they function correctly and efficiently
IT support	Provide IT support to control room operators and other staff, helping them resolve IT-related issues
IT system restoration	Restore IT systems and applications critical to grid operations
security operations	Monitor and respond to cybersecurity threats, ensuring IT infrastructure protection
Operational system security	Monitor system security limits in real-time and recalculate transfer limits based on current and upcoming system states
Capacity planning	Prepare trading capacities for the electricity market, oversee grid modelling and perform system analysis
Other	Free text entry for additional tasks not listed above

In Section 1 of the questionnaire, the participants were asked to consent to their responses being processed for scientific analysis. The second section of the questionnaire gathered information about the respondents' working role, age and years of experience. The aim of Sections 3 and 4 was to explore how operator tasks have changed over the past five years and how these tasks are expected to continue developing. Therefore, in Section 3, respondents were asked multiple-choice questions about their main tasks during normal operations, followed by questions about how these tasks have changed over the past five years and how they are expected to change in the future. The questions in Section 4 were the same as in Section 3 but related to disturbed operations (meaning alert, emergency or blackout conditions). Sections 3 and 4 of the questionnaire were developed with a grid operation expert and aimed to identify the key responsibilities of grid operators during both normal and disturbed operations. More specifically, the tasks were defined in advance by the authors and then reviewed and developed by a grid operation expert working in the TSO control room domain. Table 3 presents the different control room tasks which respondents could choose between in the multiple-choice questions in Sections 3 and 4. The aim of Section 5 of the questionnaire was to identify key support tools for grid operators during normal operations and explore how these tools have changed over the past five years and may evolve in the future. Therefore, the respondents were asked open-ended questions about the different supports used during normal and disturbed operations to gain an understanding of what support tools they use and attitudes towards them. The section also included a five-point Likert scale, in which the respondents were asked to evaluate various aspects of their experience with current support tools. Together, these questions aimed to capture a nuanced understanding of how grid operators perceive the functionality and support provided by existing systems. The questions in the Likert scale addressed perceptions of operational safety and reliability, technical stability and the tools' contribution to job performance. Additional questions explored satisfaction with the tools, their adaptability to individual needs and the adequacy of training received. The aim of Section 6 of the questionnaire was to explore attitudes towards the introduction of new tools and increased levels of automation. Using a five-point Likert scale, respondents evaluated perceived impact, effectiveness and challenges. These questions were designed to capture grid operators' perspectives on how such tools may influence their work and to gather insights into the strengths and limitations of both current and future technologies. Sections 3–6 of the questionnaire included a final question under which the respondents could add comments, while Section 7 provided the participants with an opportunity to share additional thoughts.

3.3 Data analysis

The data analysis was conducted in three main steps and followed a structured approach designed to maintain close alignment between the questionnaire design, respondents' answers and the study's research questions. The analytical process combined deductive structuring of the questionnaire data, based on predefined questionnaire areas, with inductive identification of recurring patterns within selected themes. This combination made it possible to maintain transparency and traceability while remaining attentive to issues emphasised by the respondents themselves.

First, to ensure that the analysis remained closely connected to how participants encountered and responded to the questions, all responses were categorised deductively into the main areas of the questionnaire (Appendix B). These areas were: 'current tasks and tools', 'task development over the past five years', 'expected future task development', 'desired future task development' and 'attitudes towards support tools and automation'. This step served as an analytical structuring of the material and enabled interpretations to be traced back to how questions were formulated and answered.

Second, for the theme 'current tasks and tools', the responses were grouped into four clusters: 'balancing tasks', 'overall operations oversight and reporting', 'power capacity planning and calculation tasks' and 'switching tasks'. These clusters reflected the main types of tasks the respondents perform today and the tools they use to carry them out. This provided an overview of existing work practices and served as the basis for interpreting later reflections on task development. Within the categories 'Task development over the past five years' and 'expected future task development', the responses were organised according to the same overarching task types 'balancing tasks', 'overall operations oversight and reporting' and 'power capacity planning' and 'calculation tasks'. The cluster 'switching tasks' was not included because the respondents reported no changes in their switching-related tasks. Organising responses according to predefined questionnaire themes ensured traceability between data and analytical categories. Since these themes were aligned with the questionnaire's structure, responses were categorised directly into the corresponding theme. For example, answers concerning task developments over the past five years were assigned to the theme 'task development over the past five years', while responses addressing expected future task development were categorised under 'expected future task development' and so forth. Each response was manually assigned to the relevant themes. This approach was considered appropriate given the limited number of responses and allowed for a detailed and direct interpretation of the content. An inductive analysis was applied to further analyse the theme 'desired future task development'. The responses were analysed inductively, allowing for emerging themes and to identify recurring needs and ambitions that cut across individual answers. Responses converged around three recurring areas of needs and ambitions: 'process efficiency', 'automation' and 'information presentation'. The theme 'attitudes towards support tools and automation' was divided into two sub-themes reflecting the distinction respondents made between their perceptions of support tools and automation more broadly.

Third, the Likert scale responses from Sections 5 and 6 of the questionnaire were grouped into the three thematic areas: 'current tools', 'introduction of new tools' and 'attitudes towards automation' (Figures 2–4) to identify patterns in how the respondents perceive and interact with their tools. The Likert-scale items were used descriptively and served to complement the main contribution of the study: the open-ended questions. The Likert-scale results thereby supported the qualitative analysis of the themes 'desired future task development' and 'attitudes towards support tools and automation'.

Quotes provided by the respondents were also used as illustrative examples and clarifications.

4 Results

The results are presented in five sections, structured around the five themes described in the Method section:

1 current tasks and tools

2 task development over the past five years

3 expected future task development

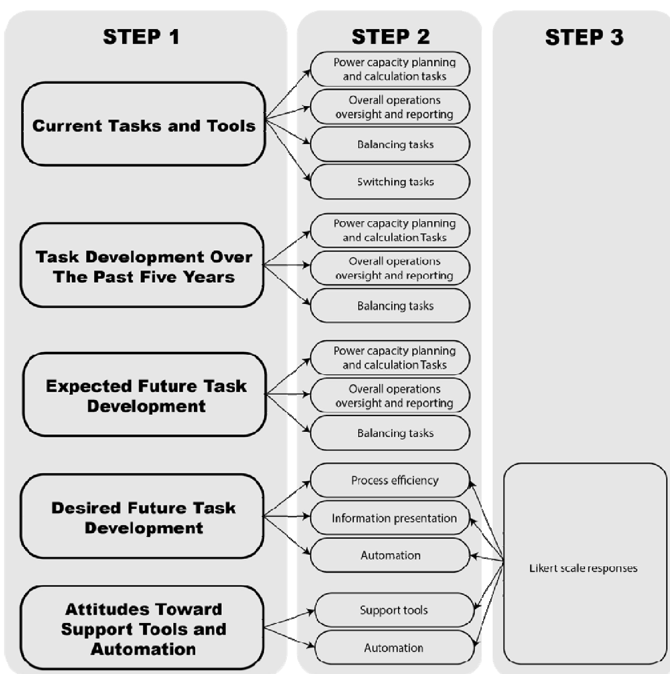
4 desired future task development

5 attitudes towards support tools and automation (Figure 1).

4.1 Current tasks and tools

The mapping of respondents' current work revealed a variety of operator titles and the tasks associated with their roles varied. Because of this variation, the results are presented as descriptions and developments of tasks rather than roles. Appendix A summarises which tasks each respondent reported doing during normal (N) and disturbed (D) system conditions. Across the 15 respondents, four broad task clusters emerged: overall operations oversight and reporting tasks; balancing tasks; switching tasks; and power-capacity planning and calculation tasks.

Figure 1 Structure of the data analysis and results



> Responses were initially sorted into the main thematic areas of the questionnaire: current tasks and tools, task development over the past five years, expected future task development, desired future task development and attitudes towards support tools and automation and then further categorised. The Likert-scale items supported the qualitative analysis of the themes, desired future task development and attitudes towards support tools and automation.

The tasks associated with overall operations oversight mainly related to engineers on duty but also included a specialist, a power system operator and a respondent working with switching and disturbance management. Eight respondents (R2, R4, R7-R12) described responsibilities related to overseeing overall system operations and six (R7–R11, R13) mentioned reporting duties. Common tools in normal operation were supervisory control and data acquisition (SCADA), market tools, decision-support systems, operational guidelines and communication with neighbouring countries. During disturbances, the same tools were used alongside a European awareness system.

Four respondents (R1, R3, R4, R13) reported involvement in balancing tasks such as load balancing (R1, R3, R4), emergency balancing (R1, R3, R4, R13), frequency control (R1) and reserve management (R1, R3). These involved maintaining grid stability and responding to production-consumption fluctuations amongst the respondents. Tools included SCADA, forecasting tools, reserve market systems and documentation systems. Additional internal and market communication tools were used during disturbances.

In the switching tasks cluster, four respondents (R2, R5, R6, R13) reported involvement in operational switching tasks and five (R2, R4, R5, R6, R13) described involvement in emergency switching to reroute power or restore the grid. Three respondents (R2, R5, R6) reported involvement in safety switching. Their core tools during both normal and disturbed operations were SCADA, phone communication, guidelines and contact with on-site maintenance personnel.

In the power-capacity planning and calculation tasks cluster, five respondents (R9, R14, R12, R14, R15) reported being responsible for capacity planning, including preparing trading capacities, grid modelling and system analysis. Seven respondents (R4, R7, R10-R12, R14, R15) reported being responsible for operational system security, which means monitoring the system security limits in real-time and recalculating transfer limits based on current and upcoming system states. Their primary tools were SCADA, flow-simulation tools and guidelines, which were used in both normal and disturbed operations.

4.2 Task development over the past five years

4.2.1 Balancing tasks

The analysis confirmed that the electric power system has become less predictable, primarily due to the increase in renewable energy production. Additionally, the task of monitoring and adjusting the grid frequency to stay within acceptable limits was reported to have changed due to the introduction of the new mFRR model. The task of managing and deploying reserve power sources to handle unexpected consumption spikes or production drops has changed due to a lack of reserves. For instance, one respondent noted: “It is becoming more difficult to balance production and consumption because of renewable energy sources like wind power. This requires more monitoring and has become more stressful. Also, a lot of new tools have been introduced” (R3).

4.2.2 Overall operations oversight and reporting

The analysis revealed that operators have experienced a shift towards more data-driven work with partly immature tools, increased attention to electricity prices in daily operations, more systematic logbook routines and a rise in both the number of events and the demands for documentation, particularly under stress. Two respondents also observed that reporting in the logbook is more systematic and is now followed up with daily meetings between the TSO organisations. One respondent added: "We are better trained for documenting during stress" (R7) and another noted that there are: "More events and more things to report" (R11).

4.2.3 Power capacity planning and calculation tasks

The analysis suggested that the introduction of the new, flow-based capacity calculation method has affected the capacity calculation process, with one respondent remarking that: "With the new 'flow-based' capacity calculation method, the whole capacity calculation process has changed completely with new tasks, new tools, new sub-processes, more international cooperation and new, daily meetings" (R15). Additionally, the analysis demonstrated that, thanks to better tools and observability (and given the current and upcoming system states), the task of monitoring the system security limits in real-time and recalculating transfer limits has become easier. Moreover, analysis showed that having a dedicated 24/7 person recalculating limits has made the process more efficient.

4.3 Expected future task development

4.3.1 Balancing tasks

The analysis indicated that respondents expect their balancing tasks to change significantly. This was due to the introduction of higher levels of automation and the anticipated new roles, better tools and more complex calculations, plus the challenges of the green transition and the need for improved training and system integration. The respondents reported that balancing tasks are expected to be mostly automated in the future. Furthermore, one respondent mentioned that: "The new balancing model starting this year will change almost everything" (R3). One respondent commented that: "New processes for balancing the system and further development of capacity allocation processes will affect the work. More or less stressful? We'll see" (R14). The respondents also stated that, with the introduction of automatic balancing, much more is required in the pre-balancing timeframe, such as solving local congestion and handling fluctuations at very short notice. One respondent mentioned: "We will maybe have to prepare for disturbed operations while still in normal operation" (R9).

4.3.2 Overall operations oversight and reporting tasks

Regarding reporting, the analysis showed the respondents noting that the initial reporting will always start in the control centre but that they expected better support from the back office. One respondent also commented that: "Better models and systems will enable faster and more accurate calculations, making it easier to find the most optimal countermeasure for different events. The system will propose proper actions" (R7). Moreover, the analysis showed that respondents anticipated that the green transition would introduce new challenges and that the operator's responsibility would be to assume control when automation fails. For example, one respondent mentioned: "The green transition will introduce new challenges. We will probably have more operators, with new roles, to supervise. The SCADA and other tools and systems are more autonomous and our role is to take over when it fails to deliver. That requires more training for rare events." (R7).

4.3.3 Power capacity planning and calculation tasks

The analysis revealed that operators foresee a continuing development of the flow-based calculation method, which will change the tasks of capacity planning. One respondent wrote that: "We've introduced flow-based on the day-ahead market. We will introduce it on both Intraday and for balancing in the future. This will definitely entail new tasks" (R15).

The respondents reported that the duties associated with switching tasks had not changed in the last five years and that no future changes were expected.

4.4 Desired future task development

4.4.1 Process efficiency

The analysis revealed that the respondents constantly check and validate production and consumption forecasts and that this task (currently performed by operators) is expected to become even more challenging as reserve activation begins to rely on these forecasts automatically. One respondent noted, "Much of the time goes to checking and validating the production and consumption forecasts. This will be more of a problem when reserve activation is done with the forecasts automatically" (R1). The current reliance on manual double-checking was seen as inefficient, with another respondent stating: "We operators double-check everything. I'd like to slim down many processes and automate them rather than having human operators double-check numbers" (R15). There was a shared vision of a more streamlined workflow, where calculations and models are trusted without repeated manual intervention. As one respondent put it: "In a perfect world, we calculate and model once and trust the processes" (R15). The perception that automation may increase task efficiency is partially supported by responses to the Likert item, "I believe that support tools with higher levels of automation will make my tasks more efficient". A majority among the respondents (12 out of 15) indicated agreement or strong agreement, while the remaining three respondents selected a neutral position. None expressed disagreement (Figure 4).

4.4.2 Automation

The analysis revealed that operators have a strong desire for increased automation across several operational areas. The respondents emphasised that many routine tasks could be delegated to automated systems to reduce human error and improve efficiency. This includes not only forecast validation but also alarm handling and system balancing. One respondent remarked: "Everything needs to be automated because we can't do the same things we are doing now manually every 15 minutes" (R3). There was also recognition that current balancing mechanisms may not be sufficient in future scenarios. As one respondent explained: "We will have to add a new level of automation to handle situations in which the current balancing [is] not sufficient" (R9). Thus, the overall sentiment was that while human oversight remains important, automation is essential to meet the demands of increasingly complex operations.

4.4.3 Information presentation

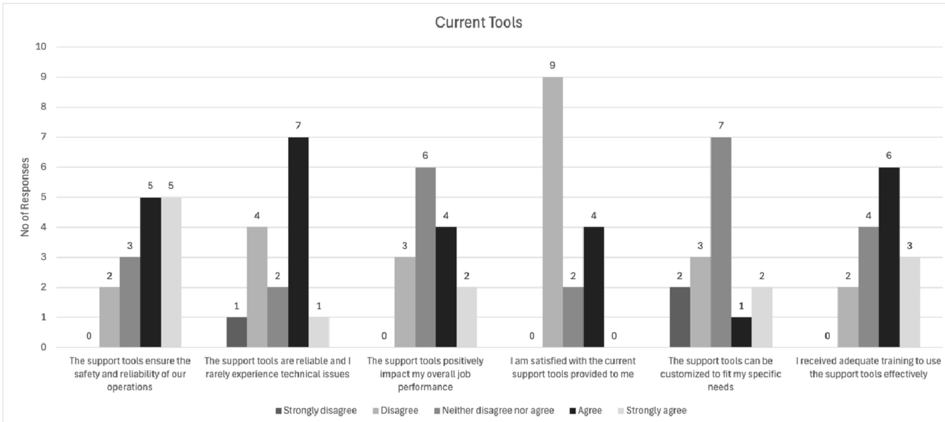
The analysis also indicated the need for better presentation of operational data and improved observability. The current systems were described by the operators as lacking clarity and responsiveness, particularly in how alarms are managed. One respondent commented: "The SCADA alarms could be better handled and presented – today we have the same prioritisation for a large number of events, making it difficult for the operators to know what to react to" (R7). Alongside alarm handling, respondents called for enhanced tools for power system analysis and more effective visualisation of required information. These improvements were seen as critical to enabling operators to work more efficiently and respond more accurately to system conditions.

4.5 Attitudes towards support tools and automation

4.5.1 Support tools

The analysis indicated that respondents perceive there to be too many support tools and express concerns about their reliability. One respondent noted that: "Unfortunately, the systems are very old and the new systems are often introduced without proper introduction to the operators" (R15). Another respondent expressed a desire for: "More customisation and more reliability" (R11). This variability in perceptions is also reflected in responses to the Likert item "The support tools positively impact my overall job performance". Four respondents answered 'agree', two answered 'strongly agree,' three answered 'disagree,' and six selected 'neither agree nor disagree' (Figure 2). Responses to the item "I am satisfied with the current support tools provided to me" further suggest some reservations, with nine respondents indicating disagreement (Figure 2). Furthermore, some respondents reported frequent introduction of new tools. Eleven respondents indicated agreement or strong agreement with the statement: "We are often introduced to new support tools in the control room" (Figure 3). Despite mixed perceptions of current tools, there are some indications of a generally positive orientation towards new ones. For example, nine respondents agreed or strongly agreed with the statement "I am positive about the introduction of new support tools." The analysis also indicated that the respondents think the tools in the control room are seldom good enough and are often developed without considering what the user needs. For example, one respondent who undertakes balancing tasks noted: "They [the tools] are not designed for the end user and have a lot of bugs. When something happens, it takes too much time to fix them". (R3). One respondent added that: "Support tools are generally designed for a different power system and lack good features for congestion management and reserve monitoring" (R9). The Likert item "I believe the training provided for new support tools is sufficient" elicited a mixed response. While almost as many respondents expressed disagreement (six) as agreement (five) and four neither agreed nor disagreed (Figure 3). This pattern may suggest that experiences of training vary or that respondents may be uncertain about what constitutes 'sufficient' training.

Figure 2 Likert scale responses on the topic of 'current tools' from Section 5 of the questionnaire



4.5.2 Automation

The analysis showed that the respondents believe the level of automation will increase in the future. Eleven respondents agreed or strongly agreed with the statement: "I believe my tasks will change as support tools with higher levels of automation are being introduced" and all respondents answered that they 'Agree' or 'Strongly agree' with the item "I believe that support tools with higher levels of automation will become increasingly common" (Figure 4). The analysis also suggested that the grid operators are mainly optimistic towards future automation. Their positive attitudes towards automation were supported by the results from the Likert item "I believe the introduction of support tools with higher levels of automation improves the safety and reliability of our operations" may indicate a tendency towards agreement, with nine respondents selecting 'Agree' or 'Strongly agree'. A similar pattern can be observed for the item "I believe that support tools with higher levels of automation will make my tasks more efficient", where 12 respondents indicated agreement or strong agreement (Figure 4). The analysis also revealed that respondents expect automation tools for balancing to become less burdensome as data quality and forecasting models improve. However, scepticism was also expressed. One respondent stated that: "New is not necessarily better. Having too many different 'new tools' without considering how they should work together as a whole is problematic" (R11) and added that: "More automation often means more things can go wrong. If the reliability were higher, I think there would be more acceptance for more automation. There is a lot of frustration when complicated systems spit out the wrong answers or stop working when we rely on them. The skills which will be developed with more automation are bug-fixing and learning exactly how the algorithms work in order to identify problems. I am not convinced that these are the types of skills operators want to learn". Finally, the analysis indicated that operators' concerns about the impact of automation malfunctions on control room operations. Respondents highlighted that as more tasks are automated and operational timeframes become shorter, errors may become more difficult to manage. One participant expressed this as: "Automation malfunction situations will challenge control room operations when more tasks are being automated and time dimensions are shorter [shorter trading and settlement period]"(R13). Despite these concerns, the analysis suggested that most respondents described a need for automation due to the increasing volatility in the system with more renewables and other types of markets. One respondent commented that: "The manual operation is a thing of the past, when flows were predictable and the generation was easy to regulate (hydro). I see many challenges getting there, though. Will the automation work? Will we keep the manual fallback procedures fresh or will we forget how to do it without automation?" (R14). However, one respondent who was convinced that more automation is necessary, stated that: "This is a very conservative industry that is slowly adapting to the improved, digitalised and automated future" (R15).

Figure 3 Likert scale responses on the topic of 'tool introduction' from Section 6 of the questionnaire

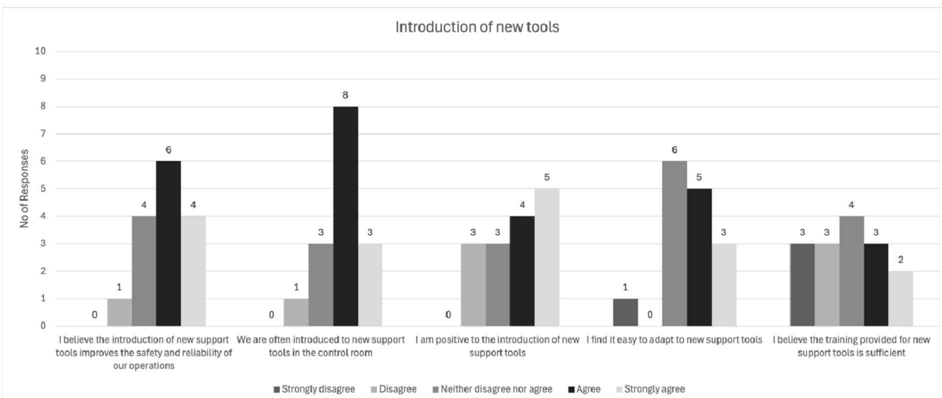
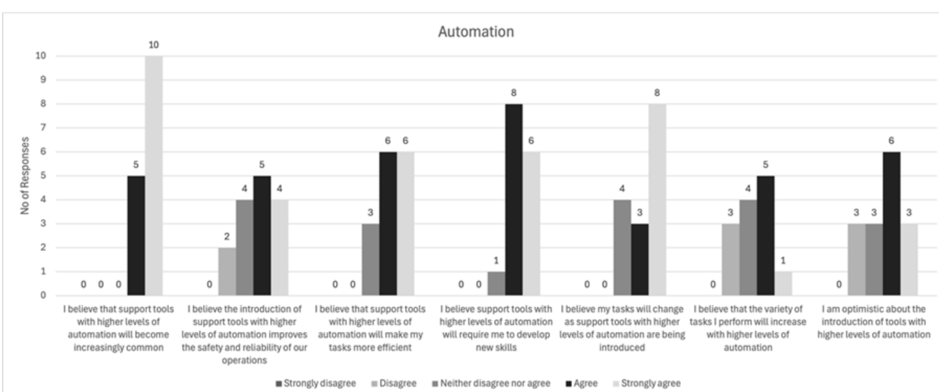


Figure 4 Likert scale responses on the topic of 'automation' from section 6 of the questionnaire



5 Discussion

The purpose of this study was to explore grid operators' own perspectives on how their tasks and tools are evolving in response to changes within the power system. Specifically, the study investigated how operator tasks have changed over the past five years, how they are expected to continue developing, operators' trust and attitudes towards existing tools and those incorporating higher degrees of automation in future systems and how operators perceived that new tools were affecting their tasks.

5.1 Historic task development – culturally shaped trust

The overall findings suggest that operator tasks have undergone changes in recent years and are perceived as likely to continue evolving, with respondents indicating expectations of increased automation. The results further indicate that operators hold ambivalent views: they recognise automation as necessary, yet at the same time express concerns about its risks and limitations. Control room operators work in a socio-technical environment where shared narratives may play a role in shaping collective expectations, as suggested by some patterns in the responses. The theme in the responses that tools have 'always been a problem' could be interpreted as reflecting elements of a shared or historically shaped understanding. Reported challenges such as insufficiently tested tools and increasing system volatility may provide some context for this cautious stance. These patterns may be indicative of broader changes in how operators perceive their role, although the present data does not allow firm conclusions on organisational transformation. These findings are broadly consistent with prior research suggesting that trust in automation is culturally influenced (Zuboff, 1988) and shaped by the long-term experiences of a group of people (Riley, 1996). Trust calibration therefore depends on organisational culture and previous experience of tool implementations.

5.2 Expected task development – implicit attitudes and role identities

The results of this study revealed that automation, such as the new automated mFRR model, is affecting balancing tasks. While operators viewed automation as essential for managing this volatility, they also raised concerns about skill retention, system reliability and trust in automated processes. Trust in automation is shaped not only by observable performance but also by implicit, often unconscious, attitudes and when system reliability is uncertain, operators with more positive implicit attitudes are more likely to rely on automation (Merritt et al., 2013). This perspective may be useful in interpreting some of the patterns observed in the responses, as grid operations become both more automated and more complex, highlighting the need to understand the psychological and experiential factors that shape operator trust. The anticipated evolution of balancing tasks also implies that a shift in operators' competencies may be required. Traditional manual skills risk gradual degradation, while new competencies, such as interpreting automated outcomes, monitoring system behaviour and troubleshooting, are becoming central to operational work. Respondents indicated expectations of notable changes in their professional roles, driven by both automation and the growing complexity of the power system. The study results could suggest that operators anticipate that advanced systems will increasingly conduct modelling, analysis and calculations, leaving operators responsible for overseeing automation and intervening when failures occur. Implicitly, respondents articulated concerns aligned with classical ironies of automation (Bainbridge, 1983), reflected in their comments on deskilling concerns and how to keep the manual fallback procedures fresh. This is close to the irony that automation simultaneously removes operators from hands-on control while making their intervention more critical during failures.

Comments such as: "The skills which will be developed with more automation are bug-fixing and learning exactly how the algorithms work in order to identify problems. I am not convinced that these are the types of skills operators want to learn", might reflect a clash between operators' tasks in an automated grid and operators' professional identity. These concerns may indicate that automation is perceived to affect not only task execution but also aspects of how operators understand their professional role. Several responses point to a potential shift away from traditionally valued forms of expertise, such as manual system interaction and towards monitoring and interpreting automated processes. Comments describing a move towards 'bug-fixing' and understanding algorithmic behaviour can be interpreted as reflections on how work roles might be changing. Changes in responsibility, control and task structure may therefore have implications not only for performance but also for how operators interpret and make sense of their work (Weick, 1995). For instance, comments describing a shift from current work towards 'bug-fixing' and learning algorithmic logic illustrate how operators actively reframe their role to maintain coherence between past professional identities and emerging task demands. Rather than merely expressing resistance to automation, these accounts reflect efforts to reconcile new forms of work with established understandings of what it means to be a skilled grid operator. It is consequently of importance that TSO organisations design not only the technical support tools but also the task allocation between operators and machines and organisational structures surrounding the technical tools. Furthermore, such a comment may connect to the need for explainable AI in future control room contexts. The goal with explainable AI is to enable humans to understand the underlying explanatory factors of why an AI decision has been made (Holzinger et al., 2022). According to the study results, operators are expected to trust systems whose inner workings they do not understand. This indicates a potential for future investigation of how explainable AI could be a solution for future control room systems. Future work could potentially further develop this area by exploring how transparency mechanisms influence operator trust calibration in highly automated control room environments.

5.3 Desired future task development – calibrated trust

The operators' ambivalent views about increased automation could suggest an underlying struggle to calibrate trust appropriately. Trust in automation is shaped by expectations of reliable support when there is uncertainty (Lee and See, 2004). Nevertheless, a significant portion of the respondents maintained a belief in automation's potential to reduce workload and enhance efficiency, provided that implementational challenges, particularly those related to tool readiness and reliability, are adequately addressed. The results also indicated that the respondents desire processes that can be trusted without extensive manual verification. The Likert scale responses may imply that operators view automation as a key enabler of more efficient tasks (for example, in response to the item "I believe that support tools with higher levels of automation will make my tasks more efficient”, 12 respondents agreed or strongly agreed, while the remaining respondents neither agreed nor disagreed). Prior research underscores the risks of over-trust in automated systems, noting that it can lead to compliance behaviours that compromise safety. It also emphasises that operators should critically evaluate and cross-check automated recommendations rather than accept outputs at face value (Bahner et al., 2008; Onnasch et al., 2014; Wickens et al., 2015). Therefore, a certain critical attitude towards system outputs in grid operations is desirable to avoid complacency and maintain operational vigilance. This, despite respondents’ hopes for less double-checking, as indicated in the results. Taken together, these findings may describe a tension between research perspectives on human-automation collaboration; they emphasise scepticism and continuous verification and the aspirations of the respondents of this study for automation that reduces the need for double-checking. Since sensemaking is tied to how individuals understand their roles and professional identities (Weick, 1995), this tension may point to a potential tension between how operators would like their role to be enacted (with less double-checking) and how their role ought to be shaped when accounting for concerns about complacency and safety in highly automated systems (requiring continuous verification).

5.4 Study limitations

While this study provides insights, it has some limitations. In general, the results may be considered credible even with a bounded sample, since the data collection focused on grid operators’ own experiences, including many open-ended questions. Furthermore, the analysis was conducted with a clear focus on recurring themes in the material, such as changing work roles, trust in automation and organisational conditions. The results suggest a high degree of consistency among respondents, while also highlighting variation in experiences and attitudes, which further strengthens credibility. This can be related to established concepts such as trust, professional identity and socio-technical change, contributing to the interpretations appearing reasonable. Transferability in the study is supported through a clear description of the study context, sample and participants. The study included 15 grid operators working within Nordic TSO organisations, in a context characterised by an increasing share of variable electricity generation, growing automation and ongoing changes in control room work. Although the findings are not statistically generalisable, the detailed account of work tasks, technological changes and organisational challenges enables the reader to assess the extent to which the results may apply to other, similar contexts, such as other TSOs or safety-critical control room environments. Transferability thus lies in the richness of the contextual description rather than in the size of the sample. The geographical scope of the study is limited to a Nordic TSO context, which may have influenced the findings. The transferability of the findings to TSOs in other geographical or regulatory contexts should be approached with caution. Nevertheless, the core socio-technical themes identified are likely to resonate beyond the Nordic region, given the global shift in increasing levels of volatile power, the introduction of automation and the similarities of other studies on the ‘future grid operator role’ (for example, Prostejovsky et al., 2019; Stevens-Adams et al., 2015). As described in the method section, a user-centred questionnaire was identified as suitable due to the limited accessibility of this specialist group and since operators hold first-hand insights into their own work practices. For follow-up studies, semi-structured interviews could provide deeper accounts of individual experiences and workplace observations would likely reveal tacit practices and informal adaptations that operators rarely articulate. Also, focus groups or workshops could highlight the social interactions that are important in control room contexts. Given the exploratory nature of the questionnaire data, future research using interviews, observations or mixed methods could further unpack how operators engage in sensemaking and negotiate their professional identities in increasingly automated control room environments.

6 Conclusions

This questionnaire study explored grid operators' own perspectives on how their tasks and tools are evolving in response to changes within the power system. The overall results indicate that grid operators are experiencing a transitional period in which automation is increasing and tasks are shifting. Operators want reliable, supportive automation but not at the cost of losing essential skills. Some of the respondents question whether emerging automation-related skills, such as debugging and understanding underlying algorithms, align with what they want to learn as operators. It is suggested in the discussion that tasks and tool shifts influence not only what operators do but may also influence how operators make sense of their role and identity. Traditional manual skills are potentially becoming less central, while competencies related to interpreting automated outputs, monitoring system behaviour and troubleshooting are growing in importance. The study also explored socio-technical ripple effects in TSO control rooms: technological developments seem to reshape operator work, task allocation and organisational structures. As a result, organisations should design not only the technical tools themselves but also the distribution of tasks between humans and automation, as well as the organisational structures that support these evolving roles. Operators' changing tasks and competencies, together with organisational structures, should evolve in parallel with technology implementations. A user-centred approach will be essential to align system goals with operators' everyday work practices to ensure safe and reliable operation. Future research should further examine how operators understand and redefine their roles in increasingly automated control rooms and how system transparency can be designed to foster well-calibrated trust.

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Declarations

The authors report no conflict of interest.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used Microsoft CoPilot to review the language. After using this service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

All participants provided informed consent prior to taking part in the study. Participation was voluntary and consent was obtained digitally: respondents were asked to press 'Yes' to confirm their willingness to participate and proceed to the questionnaire or 'No' to decline. Only respondents who selected 'Yes' were able to complete the survey. The consent procedure included information about the purpose of the study, data handling and anonymity. No identifiable or personal data was collected and all responses were processed anonymously.

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Appendix A

The tasks of the respondents

Respondent ID	*Role*	*Load balancing*	*Emergency load balancing*	*Frequency control*	*Reserve management*	*Operational switching*	*Emergency switching*	*Safety switching*	*Overseeing overall operation*	*Reporting*	*Operational system security*	*Capacity planning*
R1 (N)	Balancing engineer	Yes	-	Yes	Yes	-	-	-	-	-	-	-
R1 (D)		Yes	Yes	-	Yes	-	-	-	-	-	-	-
R2 (N)	Specialist	-	-	-	-	Yes	-	Yes	Yes	-	-	-
R2 (D)		-	-	-	-	-	Yes	-	Yes	-	-	-
R3 (N)	Balance operator	Yes	-	-	Yes	-	-	-	-	-	-	-
R3 (D)		Yes	Yes	-	Yes	-	-	-	-	-	-	-
R4 (N)	Power system operator	Yes	-	-	-	-	-	-	Yes	-	-	Yes
R4 (D)		-	Yes	-	-	-	Yes	-	-	-	Yes	-
R5 (N)	Switching engineer	-	-	-	-	Yes	Yes	Yes	-	-	-	-
R5 (D)		-	-	-	-	Yes	Yes	Yes	-	-	-	-
R6 (N)	Switching engineer	-	-	-	-	Yes	Yes	Yes	-	-	-	-
R6 (D)		-	-	-	-	Yes	Yes	Yes	-	-	-	-
R7 (N)	Engineer on duty	-	-	-	-	-	-	-	Yes	Yes	Yes	-
R7 (D)		-	-	-	-	-	-	-	Yes	Yes	Yes	-
R8 (N)	Grid supervisor/ engineer on duty	-	-	-	-	-	-	-	Yes	Yes	-	-
R8 (D)		-	-	-	-	-	-	-	Yes	Yes	-	-
R9 (N)	Engineer on duty	-	-	-	-	-	-	-	Yes	Yes	-	Yes
R9 (D)		-	-	-	-	-	-	-	Yes	Yes	-	-
R10 (N)	Engineer on duty	-	-	-	-	-	-	-	Yes	Yes	Yes	-
R10 (D)		-	-	-	-	-	-	-	Yes	Yes	Yes	-
R11 (N)	Engineer on duty	-	-	-	-	-	-	-	Yes	Yes	Yes	-
R11 (D)		-	-	-	-	-	-	-	Yes	Yes	Yes	-
R12 (N)	Grid supervisor	-	-	-	-	-	-	-	Yes	-	Yes	Yes
R12 (D)		-	-	-	-	-	-	-	Yes	-	Yes	Yes
R13 (N)	Switching and disturbance management	-	-	-	-	Yes	-	Yes	-	Yes	-	-
R13 (D)		-	Yes	-	-	-	Yes	-	-	Yes	-	-
R14 (N)	Power system analyst	-	-	-	-	-	-	-	-	-	Yes	Yes
R14 (D)		-	-	-	-	-	-	-	-	-	Yes	Yes
R15 (N)	Power system analyst	-	-	-	-	-	-	-	-	-	Yes	Yes
R15 (D)		-	-	-	-	-	-	-	-	-	Yes	Yes

Note: (N) = normal operations, (D) = disturbed operations.

Appendix B

Current and future operator tasks in the TSO control room

The aim of this questionnaire is to gain insight into the current and future tasks and support tools of control room operators in the TSO domain as input to the design of future control rooms and takes about 10 minutes to fill in. The target group includes all roles working in Nordic TSO control rooms.

- The questionnaire is part of a 5-year research project named [project name and number]
- The questionnaire closes on Friday January 31, 2025.
- Scientifically responsible for this study is [name]
- Contact person for this study is [name and e-mail address].

Reach out if you want to withdraw your response or have any questions or comments.

Consent

By pressing 'yes' and then completing the questionnaire, I consent to my responses being processed by [university] for scientific analysis. By pressing 'no,' I choose not to participate. The responses are handled completely anonymously and cannot be traced back to you as an individual.

a Yes

b No

Introduction

- What is your age?

  (Free text answer)

- Please select your highest level of education and specify the field of study relevant to your job
  - a High school
  - b Bachelor's degree
  - c Master's degree
  - d Doctorate degree
  - e Other
  - f Prefer not to answer/do not know
- What is your country of employment?
  - a Sweden
  - b Norway
  - c Finland
  - d Denmark
  - e Iceland

- How many years of experience do you have in the control room?
  - a Less than 1 year
  - b 1–4 years
  - c 5–9 years
  - d 10–14 years
  - e 15–19 years
  - f 20–24 years
  - g More than 24 years
  - h Prefer not to answer/do not know
- What is your formal role(s) in the control room?
  (Free text answer)

Tasks during normal operations

For the following questions, please refer to your tasks during normal operations.

- What are your main task(s) in the control room during normal operations?
  (Multiple choice; Choose 1-3 tasks)
  - a Load balancing: maintain grid stability by matching electricity production with consumption in real-time.
  - b Emergency load balancing: rapidly adjust the balance between electricity production and consumption to stabilise the grid.
  - c Frequency control: monitor and adjust the grid frequency to stay within acceptable limits.
  - d Reserve management: manage and deploy reserve power sources to handle unexpected consumption spikes or production drops.
  - e Operational switching: execute planned switching orders to reconfigure the grid for maintenance or other operational needs. Switching operations for voltage regulation.
  - f Emergency switching: execute emergency switching operations to reroute power and/or switching operations during the restoration phase after larger disturbances.
  - g Safety switching: implement safety protocols and switching procedures (switching orders) to ensure safe working conditions for maintenance crews.
  - h Overseeing overall operation: oversee the overall operation of the control room, responsible for the overall delivery.
  - i Reporting: document and report on the status of the grid, incidents and any actions taken during the shift.
  - j IT System monitoring: continuously monitor IT systems and applications to ensure they are functioning correctly and efficiently.
  - k IT Support: provide IT support to control room operators and other staff, helping them resolve any IT-related issues.

l IT system restoration: focus on restoring IT systems and applications critical to grid operations.

m Security operations: monitor and respond to cyber security threats, ensuring that the IT infrastructure is protected against cyber-attacks.

n Operational system security: monitor the system security limits in real-time and recalculate transfer limits given the current and upcoming system state(s).

o Capacity planning: prepare the trading capacities for the electricity market. Oversee grid modelling and perform system analysis.

p Other.

- Has any of your tasks during normal operations changed in character over the last five years? How?

  (Chosen tasks from question 6 are shown, respondent can check the box of 0-3 of those)

- Do you think that any of your tasks during normal operations will change in character in the future? How?

  (Chosen tasks from question 6 are shown, respondent can check the box of 0-3 of those)

- Would you like any of your tasks during normal operations to be different in some way? If so, please describe how and why.

  (Voluntary free text answer)

Tasks during disturbed operations

For the following questions, please refer to your tasks during disturbed operations (alert, emergency, blackout)

- same questions as for normal operations but for disturbed operations.

Support tools

- List the most central support tools you currently use during normal operations (for example, SCADA system, decision supports, documents, guidelines, etc)

  (Voluntary free text answer)

- List the most central support tools you currently use during disturbed operations (alert, emergency, blackout) (for example, SCADA system, decision supports, documents, guidelines, etc)

  (Voluntary free text answer)

- What are your attitudes regarding current support tools provided in the control room?

  (Likert scale; strongly disagree to strongly agree and prefer not to answer)

  - The support tools ensure the safety and reliability of our operations
  - The support tools are reliable and I rarely experience technical issues
  - The support tools positively impact my overall job performance

  - I am satisfied with the current support tools provided to me
  - The support tools can be customised to fit my specific needs
  - I received adequate training to use the support tools effectively
- Is there anything you would like to comment about support tools?
  (Voluntary free text answer)

Introduction of support tools

- What are your attitudes regarding the introduction of new tools in general?
  (Likert scale; strongly disagree to strongly agree and prefer not to answer)
  - I believe the introduction of new support tools improves the safety and reliability of our operations
  - We are often introduced to new support tools in the control room
  - I am positive to the introduction of new support tools
  - I find it easy to adapt to new support tools
  - I believe the training provided for new support tools is sufficient
- What are your attitudes regarding the introduction of support tools with higher levels of automation?
  (Likert scale; strongly disagree to strongly agree and prefer not to answer)
  - I believe that support tools with higher levels of automation will become increasingly common
  - I believe the introduction of tools with higher levels of automation improves the safety and reliability of our operations
  - I believe that support tools with higher levels of automation will make my tasks more efficient
  - I believe support tools with higher levels of automation will require me to develop new skills
  - I believe my tasks will change as new tools are being introduced
  - I expect that the variety of tasks I perform will increase with higher levels of automation
  - I am optimistic about introducing tools with higher levels of automation
- Is there anything you would like to comment about the introduction of new tools or higher levels of automation?
  (Voluntary free text answer)

Final question

- Is there anything else you would like to add or comment?
  (Voluntary free text answer)

Thank you for your time and engagement!

May I contact you for future research studies or questions regarding your answers? Send me an e-mail: [e-mail address]