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# Rethinking Distribution Grid Operational Planning with Flexibility Resources

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**SUMMARY**

The transition to active distribution grids necessitates reevaluating planning and operation processes, where they are no longer considered independent. So, operational planning emerges as the crucial link to navigate the demanding new conditions in active distribution grids assisted by emerging technologies. Distribution grid operational planning can ensure proactive management of grid problems, faster adaptability, providing detailed information to the control centers, as system conditions change, and integrating this information into slower processes like long-term grid planning. Typically, operational planning is conducted for day-ahead, week-ahead, and seasonal time horizons. Detailed or near-real-time operational planning, on the other hand, is uncommon in today's distribution grid. Current operational planning is characterised by manual and often paper-based approaches that are translated into only offline grid reconfigurations or personnel dispatch. With the availability of measurements and sensors, distribution grids are becoming more monitored, allowing the determination of the full state of the system, i.e., all important variables such as current, voltages and powers. Also, with the wide integration of intermittent forms of energy resources and as the activation of flexibility resources becomes routine operational measures, planning the active distribution grid operation close to real-time will play a fundamental role. As the preconditions to implement a systematic and analytic operational planning process for DSOs are being established, this study drafts a process flow chart for DSO operational planning from the week-ahead to near-real-time time horizon suited for future distribution systems.

**KEYWORDS**

Active distribution grids, operational planning, flexibility resources, grid reconfiguration



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## 1 INTRODUCTION

Today's distribution grids are undergoing a transition from centralized and often predominantly fossil-fuel-based systems, to more decentralized and sustainable ones, while supplying an increasing electric load demand in a reliable manner. This transition requires distribution grids to be *active* distribution grids, which are defined by CIGRÉ Working Group C6.19 [1] as distribution grids that "have systems in place to control a combination of distributed energy resources (DERs), defined as generators, loads and storage. Distribution system operators (DSOs) have the possibility of managing the electricity flows using a flexible network topology." The transition to active distribution grids is happening against the backdrop of multifaceted challenges, which can be summarized as [2], [3], [4]:

- The continuous rise in global electricity demand, which is driven by urbanization, industrialization (e.g. hydrogen plants), digitalization (e.g. new data centers) and electrification of various sectors (e.g. all-electric transportation).
- The need for more sustainable solutions has brought the interconnection of more DERs with more uncertainty due to variable, intermittent renewable energy sources.
- More challenging loads with higher variability and/or new consumption patterns.

All these challenges mean that planning and operation practices must evolve. The distribution systems will transform progressively into a more dynamic, automated, and resilient system with the assistance of emerging information and communication technologies (ICT) [5]. But they will also have new roles and responsibilities. System planning mainly consists of all activities that involve decisions ensuring that grid capacity will meet future demand. In other words, planning has a long-term perspective e.g. forecasting the demand based on historical data, seasonality, or other relevant factors. System operation focuses on the short-term management of the existing distribution grid to meet current demand while stability and reliability are fulfilled. However, in the active distribution grids, planning and operation can no longer be considered independent processes [1]. As will be described in this paper, a systematic framework for operational planning contributes to integrating grid operation and grid planning in a consistent manner.

The process of power system operational planning includes studies, guidelines and scheduling of measures for system operation, performed ahead of real-time operation. It also includes the exchange of updated information about the system state with the control centres, as system conditions change, using SCADA and other communication channels. Today's distribution grid operational planning is characterized by manual and often paper-based processes that are mainly focused on planning switching and personnel dispatch. With the availability of measurements and sensors, Medium Voltage and even Low Voltage grids are becoming visible with the possibility of running advanced monitoring such as a state estimation that can determine all voltages, currents and angles, i.e., full observability. Also, with the wide integration of intermittent, variable energy resources, planning the distribution grid close to real-time will have paramount importance. Moreover, the opportunities for shorter-term operational planning are improved as the use of *flexibility resources* (including production and/or consumption resources, and/or energy storage [4]) become routine operational (active) measures in distribution systems. Figure 1 shows an illustration of the expected transition in operational planning, which includes a transition from reactive to more proactive processes and from manual to more automated operations.


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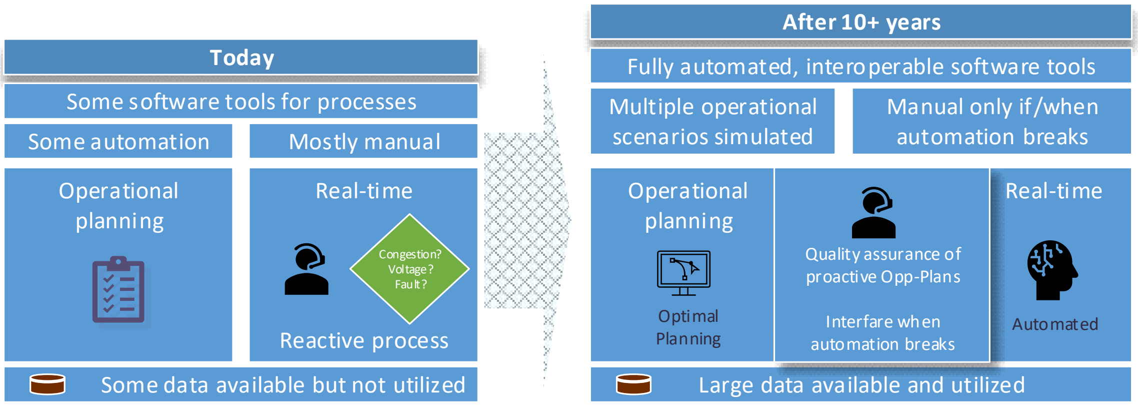

Figure 1. Operational planning practices today and expected in the future.

The objective of this study is to propose and conceptualise an operational planning framework for distribution system operators. As the preconditions to implement a systematic and analytic operational planning process for DSOs are being established, this study drafts a process flow chart for DSO operational planning from the week-ahead to the near-real-time time horizon.

To fill the gap in the current DSO planning practices on time scales day- to weeks-ahead we build upon 1) current DSO practices on these time scales (that exist but are not yet structured, connected and set in context in the form of a framework), 2) the research literature, and 3) current TSO operational planning practices (since these are currently more established than operational planning practices for lower voltage levels). We start by describing the industrial state-of-the-art (current practices) in Section 2. Then Section 3 discusses the changes required in the current operational planning processes following trends and new technological opportunities outlined in the introduction. Section 4 describes the interfaces and interactions between different planning processes, drawing upon current TSO practices and an existing framework for active distribution grid planning for inspiration. On this basis, a high-level flow chart is presented in Section 5 as a proposal for an operational planning framework for active distribution grids. Section 6 concludes the paper.

## 2 OVERVIEW OF DSO'S PLANNING PROCESSES PLANNING

This section summarizes today's DSO grid management practices across all time horizons but with a focus on the operational planning processes. The summary is based primarily on the experiences of DSOs in Norway but also includes the experiences of DSOs outside of Norway. DSOs are responsible for grid management decision processes and planning activities over different time horizons. One common way to group activities and time horizons is to distinguish between [2]: i) Long-term planning, ii) operational planning (including mid-term and short-term operational planning, and iii) real-time operation. The activities and processes performed during the different time horizons are shown in Figure 2. Note that the terms, time horizons and definitions used for the different planning and operation processes vary widely within the industry and are not clearly defined in the literature. The terminology and classification we propose below are intended to reduce potential confusion due to inconsistent and overlapping labelling of activities.



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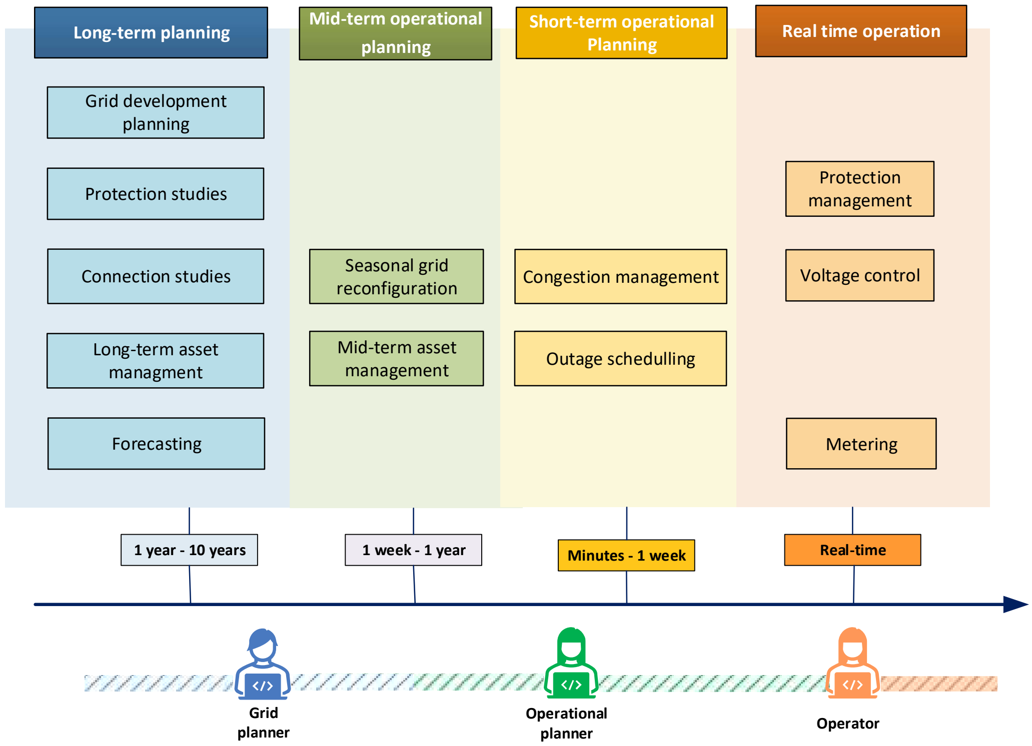


Figure 2. Traditional DSO planning processes and activities on different time horizons.

For long-term grid development planning, the relevant time scale (planning horizon) is up to several decades. Grid operation has a more short-term perspective, from days to real-time. For operational planning, the relevant time scale is typically 1 week to 1 day, and a plan or schedule is traditionally given by a sequence of set points for generator dispatch. Typical operational planning can be conducted for day-ahead, week-ahead, and seasonal time horizons. However, detailed or near-real-time operational planning in today's distribution grid is not common practice.

## 2.1 Long-term planning

We use "long-term planning" to refer to all planning activities with planning horizons of years to decades. For DSOs, such activities are part of grid development planning, which is often also referred to as "grid expansion planning" or simply "grid planning". Planning of grid development, or more generally power system development, has been defined as "taking decisions that change the system's power transfer capability through construction, upgrading, replacement, retrofitting or decommissioning of assets" [6]. Effective long-term planning necessitates a systematic examination of the type, location, and timing of such grid measures. This analysis extends beyond mere cost minimization, incorporating critical considerations such as socio-economic impacts, environmental implications, reliability enhancements, adherence to legal frameworks, and political constraints [2]. Within distribution grid planning there are different processes considering different time horizons. Over time scales of years to decades, it entails creating grid development plans based on long-term load and generation forecasts (scenarios). These two activities are displayed as *grid development planning* and *forecasting* in Figure 2. The process for connecting new grid users (demand or generation) may consider time horizons of a few years and is denoted as *connection studies* in Figure 2. Smaller modifications such as installing protection systems, could occur over even shorter time scales [2]. *Protection studies* are another activity that is part of long-term planning, e.g. short-circuit studies, protection coordination and fuse-sizing studies. Long-term planning also includes the reinvestment, replacement, renewal and refurbishment of grid assets, with a planning horizon



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that may be several years, this is sometimes referred to *as long-term asset management* activities and is denoted as such in Figure 2 [2], [7].

### 2.2 Mid-term operational planning

Most processes within the mid-term time horizon of around a year are traditionally those related to asset management. Several definitions exist of the term asset management, but here we define it as "systematic and coordinated activities and practices through which an organization optimally manages its physical assets and their associated performance, risks and expenditures over their lifecycles to achieve its organizational strategic plan" [7], [8]. *Mid-term asset management* activities with a time horizon of around a year include maintenance planning and the scheduling of the associated (planned) outages (see Figure 2). Long-term asset management plans and grid development plans also give rise to outage requests that need to be scheduled as part of the mid-term operational planning. An important concern for these activities is to prolong asset lifespans and prevent failures and unplanned outages. Another activity related to asset management is derating or uprating grid assets, or in other words changing their operational capacity limits. Planning of seasonal changes of the grid topology (i.e., *seasonal grid reconfiguration*, see Figure 2) to reduce losses or reduce the risk of congestion is also a traditional DSO activity that happens on the mid-term time scale.

### 2.3 Short-term operational planning

The time horizon for short-term operational planning may span from minutes/hours to several days ahead of real-time, serving as the preparatory phase before real-time operation activities. It involves making decisions proactively for how the grid will be operated to ensure the security of supply of the distribution system. One key task is scheduling outages that have been requested from the mid-term operational planning processes and cancelling planned outages if necessary to ensure the security of supply. (This is displayed as *outage scheduling* in Figure 2.) On the short-term time scales, outage and maintenance scheduling also entails crew dispatching. *Congestion management* activities for DSOs are traditionally limited to temporarily handling bottlenecks for certain grid assets e.g. lines and transformers, see the process in Figure 2.. Operational measures such as up/down regulation of certain distributed generators and disconnection of interruptible loads [9] are used to some extent. Short-term operational planning depends on a suitable forecast to perform proactively all the different processes, and until very recently, such forecasts have not been available to DSOs (e.g. forecasts are based on a rough assessment of weather conditions).

### 2.4 Real-time operation

Real-time operation refers to all tasks for operating the system over very short time scales, within the hour of operation (i.e., almost real-time). Over such time scales, operating conditions can be assumed to be relatively predictable and stable, including scheduled generation, load demand, and power exchange with neighbouring grid areas [2]. The actions (measures) taken are either pre-planned in the operational planning phase or based on the observed system state [10]. The primary goal is to ensure the security of supply while optimizing operational costs. Preventive control involves pre-planned actions to address potential failures or unexpected system reactions. This includes making decisions such as switching equipment or rescheduling loads. Additionally, real-time operation monitors the grid topology for unplanned outages and makes corrective control actions when they occur. The key tasks include: 1) *Voltage control* (e.g. on-load tap changing, shunt operations, and Volt-VAR optimization) 2) *Protection management* (e.g., fault detection to selectively isolate a temporary fault or locate a permanent fault) 3) *Metering* (e.g. using advanced metering infrastructure (AMI) to better



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monitor and understand customer behaviour or insights about disconnections). These tasks are displayed in Figure 2.

## 3 REQUIRED CHANGES IN EXISTING PROCESSES

In future operational planning, more interaction and overlapping in the above-mentioned processes is expected. In addition, new technological opportunities and the drivers outlined in the introduction give rise to new DSO activities and require changes in existing processes. Figure 3 gives an overview of DSOs' processes and activities in the future in a similar format as Figure 2. New processes and activities compared with Figure 2 are highlighted in purple. The potential changes required for each time horizon are described in the following subsections. Most attention is given to time horizons closer to real-time operation. For long-term grid planning and asset management processes, required changes are only within the scope of this paper when they interact with operational planning processes.

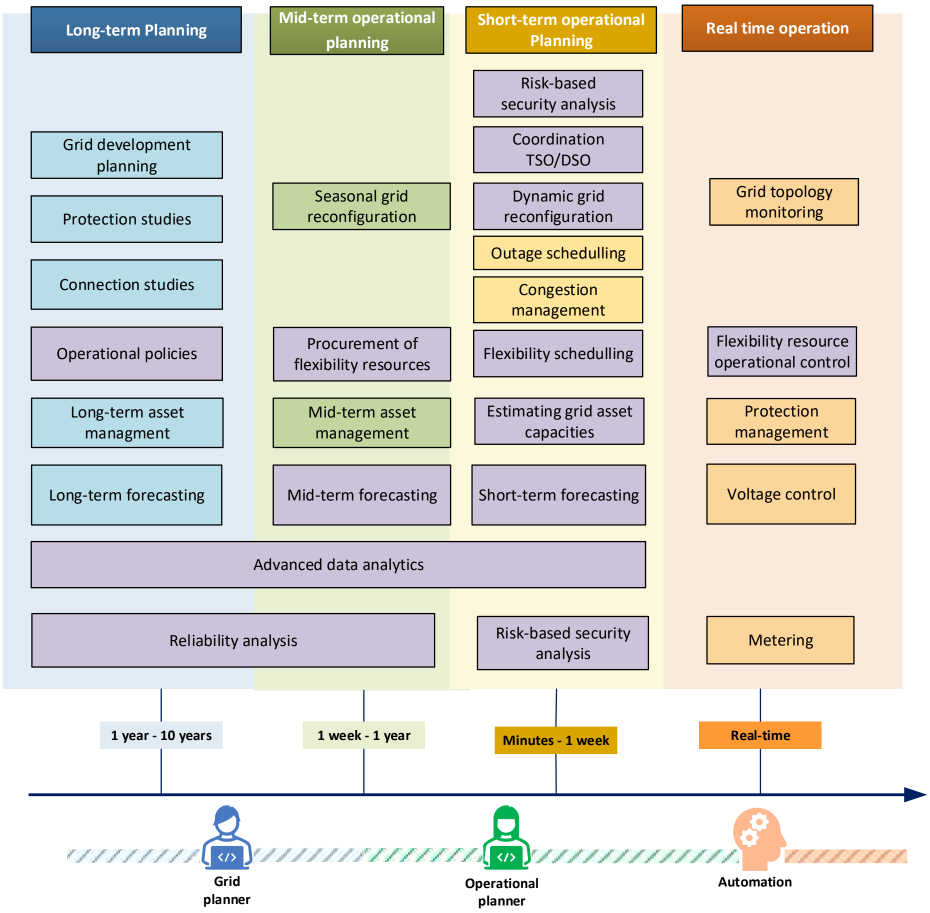


Figure 3. DSO planning processes and activities on different time horizons in the future, including both the traditional ones (also shown in Figure 2) and required changes.

### 3.1 Long-term planning

*Connection studies* will include the assessment of flexibility activation mechanisms (e.g. load curtailment for non-firm connections) and operational control requirements for flexibility resources. *Protection studies* need to consider dynamic reconfiguration, flexibility resource operational control and flexible scheduling for modifying the protection set points. *Operational policies* are an emerging concept that has been established for some Norwegian DSOs, inspired by the operational policy of the TSO, but are for most DSOs not yet well defined. *Grid development planning* should account for the operational measures (active measures) that may be available in the operational planning phase, in addition to traditional grid investment measures. All these processes can be found in Figure 3.



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### 3.2 Mid-term operational planning

*Procurement of flexibility resources* is a new process required when the DSO seeks to increase the probability that flexibility resources are available when they are needed in short-term operational planning. *Forecasting* of load and generation may be required for instance for seasonal procurement of reserves from flexibility resources. This requires more granular time resolution than forecasting traditionally done by TSOs for long-term planning. It also requires a more granular spatial resolution for DSOs than for TSOs. Moreover, *Advanced Data Analytics* can be used in both *Procurement of flexible resources* and *Forecasting.* (These processes are indicated in Figure 3.)

### 3.3 Short-term operational planning

*Forecasting* for short-term operational planning entails estimating load demand and generation from minutes ahead up to 10 days ahead. It can also include automatic forecasting of grid asset loading and voltage profiles. Forecasts can also include estimates of the real thermal capacity of grid assets to be used for setting the operational limits (Dynamic Line Rating or Dynamic Transformer Rating). *Data analytics* can involve communication networks and managing information to provide a wealth of new data, which can provide insights into the system state. Congestion management will include new operational measures: *Flexibility scheduling* involves activation of flexibility resources in the operational planning, such as requesting curtailment or shifting of load demand for grid customers on non-firm connections or bilateral agreements or activating flexibility through a local flexibility market [11]. Flexibility resources could also include batteries in the grid or distributed generation. *Dynamic reconfiguration* involves changing the positions of breakers (switches, preferably remotely controlled) within the short-term time horizon, typically to move load between neighbouring substations to alleviate congestion or optimal power flow. For congestion management and outage scheduling, DSOs may need to exchange information with the TSO and other actors. The use of microgrids for planned and unplanned outages could be part of DSOs' operational planning.

### 3.4 Real-time operation

For real-time operation with the new operational measures, there must be systems in place to remotely control breakers and to activate flexibility resources. *Flexibility resource operational control* can in the future entail modifying reactive as well as active power consumption/injection. It is also expected that *voltage control* activities will be extended to include coordinated voltage control. *Metering* could include measurements with higher time resolution (nearer real-time). Together with real-time *grid topology monitoring,* this allows better information about the system state to be fed back to the short-term operational planning, including unplanned outages as well as the actual load in the system.

## 4 INTERACTIONS BETWEEN DISTRIBUTION GRID PLANNING PROCESSES

This section reviews new interactions between planning processes on different time horizons that will determine the framework for active distribution grids. First, interactions already existing at the transmission level will be described. Then, an existing framework for long-term distribution grid planning will be described that accounts for operational measures in active distribution grids. Both will be used as inspiration when proposing the framework for the operational planning of active distribution grids in Section 5.

### 4.1 Interactions between planning processes for transmission systems

In [12] it is argued that distribution grids are becoming more similar to transmission systems with the introduction of distributed flexibility resources. These resources introduce new operational measures or control variables in the operation of the distribution grids. Flexibility



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resources that become available to DSOs are analogous to the reserves already available to TSOs (traditionally generation resources, which can also be regarded as flexibility resources) that are used for system balancing and congestion management [10].

Figure 4 illustrates how TSO planning processes at different time horizons interact. It is inspired by a similar flow chart in [10] from the EU project GARPUR that considered TSOs' reliability management processes across different time horizons. Here we have added reserves (or in other words, flexibility resources) that TSOs procure approximately on a yearly basis as an output from mid-term operational planning that is input to short-term operational planning. Another input to TSOs operational planning, which is described in [10], is operational policies that guide how transmission systems are to be operated and that inform the operational planning processes.

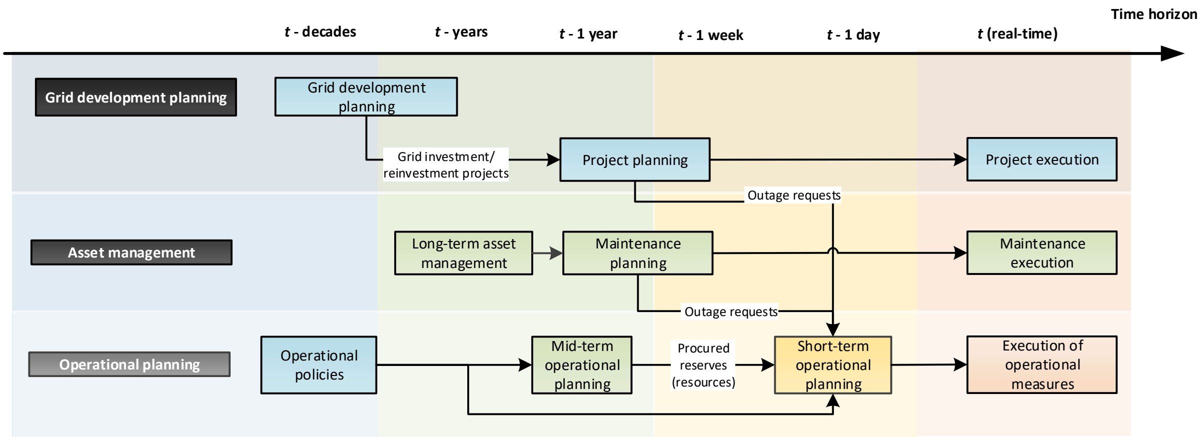

Figure 4. Relationship and interactions between system operators' planning activities at different time horizons.

Figure 4 also clarifies how each group of planning processes includes activities at different time horizons: For instance, grid development planning may initially consider a planning horizon of several decades, but for implementing the grid investment measures that are selected, more detailed planning and engineering processes with shorter time horizons (years to weeks) are required for these grid investment projects. Finally, within each day, the projects are being executed to implement the grid measures, e.g., building a new line. Similar principles apply to the execution of maintenance measures scheduled in the asset management process and executing operational measures scheduled in the operational planning process. Moreover, Figure 4 illustrates how operational planning should be coordinated with both grid development and asset management processes: Both when building new grid assets or reinforcing existing assets, or when maintaining ageing grid assets, some assets (grid components) need to be taken out of service. An important part of operational planning is to assess if and how the grid can be operated with acceptable risk concerning the reliability of supply given one or several planned grid outages.

### 4.2 Coordination between distribution grid planning and operation

Figure 5 shows a high-level flowchart of a framework for grid development planning of active distribution grids, based on [13] [9] [14]. This flow-chart describes the planning process within the box "Grid development planning" in Figure 4 and will be used as inspiration for a corresponding process within the box "Short-term operational planning". That process and the steps within will be described in Section 5. In this subsection, we will use Figure 5 to illustrate interactions between long-term grid planning and short-term operational planning. If operational measures such as the use of flexibility are to be available in the operational planning phase, they must have been selected for implementation in the grid planning phase. Grid planning should, therefore, consider these operational (active) measures as well as traditional


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grid investment measures. To assess the techno-economical costs and benefits of active measures in the grid planning phase one needs to make assumptions about how the grid will be operated with these active measures. Accurate assessment therefore requires some form of model of future operational planning processes.

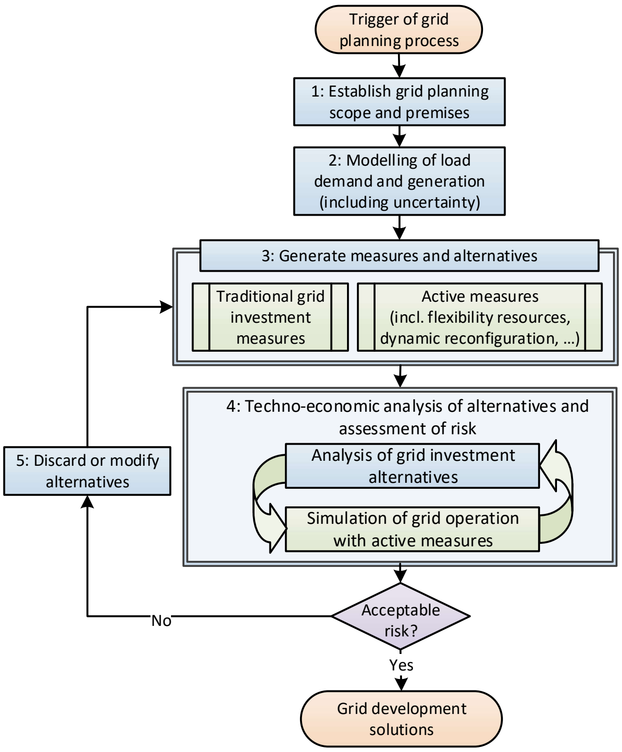

Figure 5. Framework for planning of active distribution grids, based on *[13]* and *[9]*.

## 5 PROPOSAL OF AN OPERATIONAL PLANNING FRAMEWORK

On the basis described in the previous sections, we propose an operational planning framework for active distribution grids summarized in the high-level flow chart shown in Figure 6. Here, we focus on short-term operational planning but do not restrict the framework to a specific time horizon. Instead, we parameterize the time horizon as follows: The operational planning process is triggered at a time $t_0$ before real-time operation ("$t - t_0$"). It results in a schedule for planned operational measures to implement in real-time (at time $t$) and at $M - 1$ subsequent time-steps with time resolution $\Delta t$. These time steps together span a planning horizon with duration $M\Delta t$. To give a concrete example, one could have a day-ahead operational planning process triggered at 12:00 each day to determine measures planned for the $M = 24$ hours ($\Delta t = 1$ hour) starting from 00:00 the following day. Variants of the process could be triggered at specific events rather than fixed times, and they could have a planning horizon spanning just a single time step ($M = 1$). In the future and with increasing automatization, we expect that operational planning processes become relevant for shorter time horizons (e.g., hour-ahead planning with $\Delta t = 15$ minutes or less).

The steps of the flow chart are summarized in the following. We also describe the main interactions with and inputs from other processes and activities, but details on data exchange and the tools involved are outside the scope of this paper.


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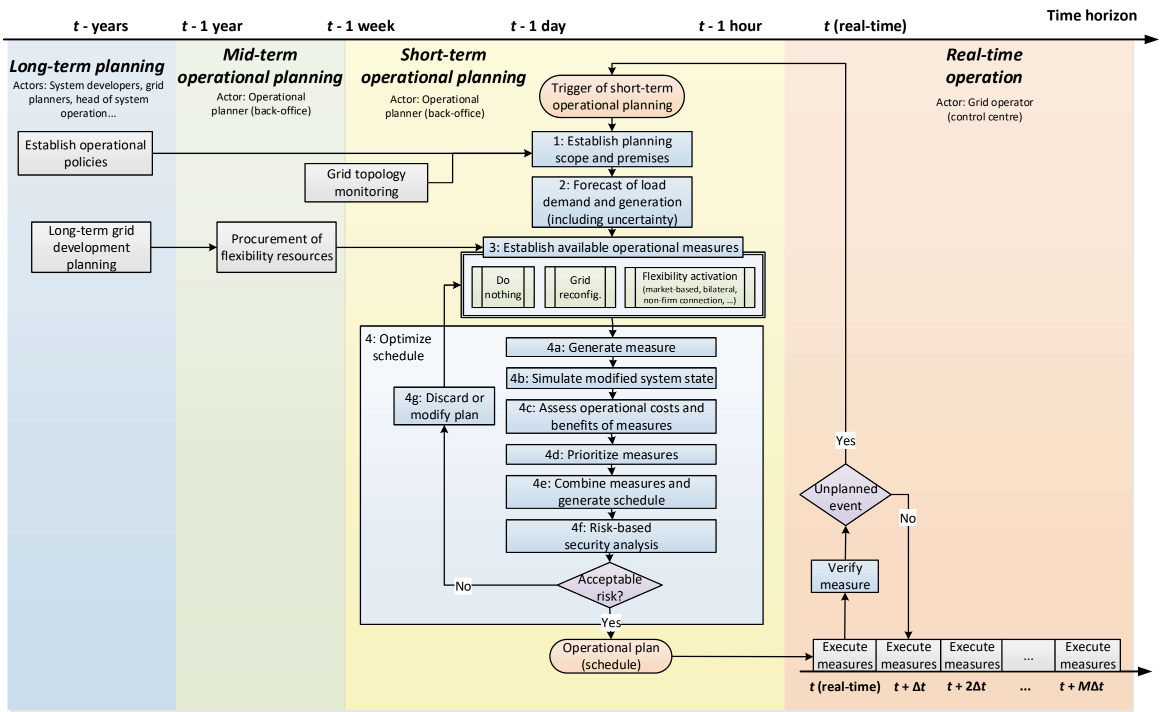

Figure 6. High-level flowchart for operational planning framework for active distribution grids.

*1*. Establish planning scope and premises: This involves defining the scope of the analysis, including the system boundary (grid area) and the necessary input data. This includes the current grid topology, given any unplanned grid outages and the current position of breakers. It also includes any planned outages for the planning horizon, which are outputs from the (e.g., week-ahead) maintenance scheduling process (cf. Figure 4). For operational planning processes, the data flow for this step should be automatized, in contrast to long-term planning processes [13] where there is more time to specify and customize for each planning study. The premises (objectives, constraints and other guiding principles) of the process are determined by the operational policy of the DSO. (Such policies would usually not be updated more frequently than once every few years.)

*2*. Forecast of load: Proactive operational planning depends upon the prediction of operational problems in the planning horizon, which in turn depends upon input data on expected load demand and generation during the planning horizon. These input data come from separate tools, services or work processes for load forecasting and estimating the current system state. Information about forecast uncertainty is an important input to be able to assess the risk associated with different operational measures.

*3*. Establish available operational measures: This step involves establishing which sets of measures are available in the operational planning horizon. Here we focus on the activation of flexibility resources and grid reconfiguration (i.e., "activating" remotely controlled breakers, being resources in a flexible grid topology). Which measures are available depends on which flexibility resources have been procured and allocated in previous operational planning processes (e.g., seasonal procurement through long-term flexibility contracts). This also depends on a well-functioning local flexibility market.

*4*. Optimize schedule: In the future, this could be a single step where an optimized schedule for operational measures is automatically generated by an optimization model. However, for transparency, this step is in Figure 6 shown as a sub-process with several sub-steps. These sub-steps can be carried out iteratively either manually or automatically. A candidate measure is first generated (*4a*) by selecting among those that are available from step 3. How the measure


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would modify the system state is simulated (*4b*) and their effectiveness in solving operational problems (i.e., their operational benefits) and their costs are estimated (*4c*). Candidate measures are then prioritized (*4d*) according to costs (and other potential criteria specified by the operational policy) and if necessary combined (*4e*). The resulting schedule may include one or more (or no) measures for one or more time steps. To check if the scheduled measures will give an acceptable risk concerning the security of supply (in accordance with the operational policy), a risk-based security assessment is carried out (*4f*). The assessment can be deterministic, e.g. by checking the compliance with security criteria such as N-1 reserve capacity requirements, given the forecasted load demand. Alternatively, the security assessment can be probabilistic by taking into account the uncertainty in load demand and/or unplanned outages to estimate the probability of violation of operational constraints. If the risk associated with the operational plan is found to be unacceptable, it is iteratively modified (*4g*) until the risk is reduced to an acceptable level. One possible modification is to cancel planned outages, for instance, due to maintenance, to increase the level of reserves in the grid.

The right-hand side of Figure 6 outlines the interaction between the operational planning process and real-time operation. In real-time operation, the planned operational measures are executed at the time they are scheduled for. Next, there must be systems in place that verify that they have in fact been executed and have been effective in solving the operational problems. However, during real-time operation, there will occasionally be events occurring that were not planned for in the operational planning phase, such as grid failures leading to unplanned outages or significant deviations from the load forecast. In this case, the schedule for subsequent steps is based on incorrect information and should not be implemented. Instead, there should be a feedback loop triggering the operational planning process to dynamically reschedule the rest of the planning horizon. This iterative operational planning process could be implemented in a rolling horizon fashion (not shown).

## 6 CONCLUSIONS

This paper reviewed the current DSO planning practices on different time scales. The authors have proposed a consistent grouping and labelling of the various processes related to operational planning at different time horizons, using the available literature, input from DSOs and current TSO operational planning practices. Moreover, it was shown the interfaces and interactions between different activities and processes between long-term planning and operational planning. In the future, more overlap and interaction are expected between different activities, but also new processes will need to be put in place. Finally, a proposal for an operational planning framework for active distribution grids is proposed. This framework focuses on short-term operational planning but does not restrict the framework to a specific time horizon since the time horizon is parametrized. Neither is the proposed framework restricted to a specific geography. However, when implementing the operational planning framework for a specific distribution system, it requires adaptations to accommodate the characteristics of that system. These adaptations hinge on various factors: The level of digitalization and technological advancements (including the deployment of communication technologies) determine which operational measures are relevant; so will system topology and the prevalence of storage, generation and demand-based resources; regulatory and policy frameworks will shape operational policies; consumer behaviour and demand patterns determine forecast needs; and the organization of the power sector influence the need for information exchange between different actors. Demonstrating concrete implementations of the framework for specific time horizons has been left to future work, as has elaborating the interactions between operational planning processes at different time horizons. Future work



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could also specify models, tools, data exchange requirements, and requirements for coordination with TSO operational planning processes.

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