Power System Control Centers and Their Role in the Restoration Process after a Major Blackout

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Abstract: - Power control centers have evolved since their ground-breaking inception in the 1960s, and they are extremely important for the operation of the power system, ensuring maximum reliability. There has been much discussion about mandating reliability requirements, but for the most part, reliability standards are already in place for electricity grid design and operation. Unfortunately, these standards do not examine in detail monitoring and control, possibly due to the false belief that reliability primarily comes from redundancies in transmission and generation. The grid can operate even more closely to its limits thanks to improved grid control and monitoring, which also increase reliability. In this paper, the significant role of the power system control centers in the event of a major blackout is discussed, proving their significance in the restoration process.

Key-Words: - Blackout, Power Energy Control Centers, Transmission System Operators, Restoration plan, Stability

Received: July 14, 2022. Revised: January 17, 2023. Accepted: February 22, 2023. Published: March 28, 2023.

1 Introduction

A practical dispatching automation system has been steadily developed over the years and is crucial to ensure the reliable operation of the power grid. However, there is a significant disconnection between the current standards and the ongoing growth of the power system, particularly in the following areas: (1) As the electricity grid's operating characteristics become more complex, the difficulty of security control follows as well; (2) in an economic dispatch, the need of energy saving is increasing; and (3) the optimization level of power system operation needs improvement, [1], [2], [3].

Worldwide, blackouts occur regularly every day, [4]. Most are brief and have minimal bearing on consumers without access to power, [5]. However large blackouts that had a big impact have happened all around the world over the past 20 years, [6], [7]. In recent decades there is a turn in renewable energy sources such as solar and wind energy to reduce the CO_2 emissions that affect the world's climate, [8]. Recent research works have shown the necessity of renewable energy sources in a power system for the reduction of CO2 emissions, [9], [10]. Using other energy sources different than fossil fuels may have risks but their use is preferable in techno-economic terms, [11]. The penetration of renewable energy sources must follow certain rules ensuring scalability and replicability, [12]. However, Variable Renewable Energy Sources (VRES) intrinsic variability decreases the power system's reliability, in severe weather conditions, [13] proving the need for energy storage and flexibility of the power system, [14]. From this fact is clear that in a power system, a blackout risk is always present with an unpredictable impact on the society and the economy, [15], [16]. It must be mentioned here that this high penetration of VRES also affects the power quality of the grid as the voltage levels, [17], [18], that may cause voltage collapse and a possible blackout, [15].

There isn't a single solution to the question of figuring out the ideal VRES penetration, [19], and quantity of storage, [20], but various standards might apply in each instance, [21]. Also, despite the fact that almost every country in Europe has a connected power system and that the European Network of Transmission System Operators for Electricity (ENTSO-E) has provided guidelines for the European grid, [22], [23], [24], [25], [26], [27], [28], [26], there is always a chance of a significant disruption or, even worse, a complete blackout. Reduction of losses and restoration time, minimization of adverse social effects, and quick and safe return of the power system to regular operation are the goals of restoration. The development of restoration methods has made extensive use of non-structured approaches, technologies, and object-oriented expert systems to accomplish the goals, [30]. As computational intelligence has advanced, some intuitive algorithms, including genetic algorithms, [31], artificial neural networks, [32], and fuzzy logic, [33], are used to restore systems. Based on the regional distribution features in space, multi-agent technologies, [34], [35], [36], [37], have been created with promise. Expert systems and heuristic rules are effectively extended by decision support systems, [38].

For the efficient use of a power system, the loadability limits must be calculated online. Maximum loadability limits were formerly calculated in power system control centers using time-consuming simulations and off-line studies, which were particularly difficult to be done when stability considerations were included. There are now straightforward applications that can determine very fast how unstable is a certain operating state.

The goal after a blackout is to restore the power system. In this process, the power system control centers (PSCC) have a significant role. In the current work the main principles of the power grid's stability, the role of the PSCCs, and basic guidelines after a blackout are presented. This paper also emphasizes the dispatcher's significance in the event of a major blackout. If a dispatcher is not competent and well-trained, the restoration plan as it will be described in section 6 will not be possible to be carried out. This work also examines and shows that a power system cannot be operated just by fast and intelligent software tools, but it also heavily relies on human skills and abilities. The restoration requires dispatchers who can adapt it to the current state of the transmission system.

The structure of this work is as follows. The significance of the PSCC and its role in the electricity system is discussed in section 2. The dispatchers, who work in these centers, are familiar with the monitoring importance and a thorough examination of the hardware and software systems that the PSCCs are based on, so they are prepared to handle any issue that might arise in the transmission system. Section 3 presents the evaluation of the power system state, and Section 4 analyzes the assessment of steady-state stability. The design of the dynamic security evaluation in a PSCC is provided in section 5, and the restoration plan and the steps that must be taken after a significant blackout are thoroughly examined in section 6. The two final sections, 7 and 8, provide the concluding notes.

2 Power System Control Centers (PSCC)

2.1 The Main Scope of a PSCC

A fundamental design feature of PSCC is that it increases system reliability and economic feasibility by performing Energy Management (EM), [39], [40], [41], [42]. The PSCC has existed for decades as the interconnected system's central decision-making body for electric transmission and production has been extended as well. It performs the tasks required for supervising and organizing the electricity system's economic and physical operations on a minute-by-minute basis. An interconnected electricity system needs carefully coordinated decision-making to maintain its integrity and economy. As a result, one of the PSCC's main responsibilities is to regulate and monitor the physical functioning of the connected grid. A high-level view of the PSCC is illustrated in Figure 1, where we can identify the SCADA system with the related telemetry and communications equipment with all the elements of the power system (circuit breakers, disconnectors, etc.) and how the software applications of the Automatic Generation Control (AGC) are implemented in it.

Figure 1 is a schematic diagram illustrating the information flow between various computer-based tasks to be carried out in a PSCC. Remote terminal units (RTUs), which encode measuring transducer outputs and opened/closed status information into digital signals and transfer them to the operations center across communication circuits, provide the system with information on the power system. The PSCC can communicate control data, such as set points to raise or lower the speed of generators, and commands to open or close circuit breakers (CBs). Analog measurements and breaker/switch status indications are also data entering the control center. The Automatic Generation Control (AGC) program must use the analog measurements of generator outputs directly, but all other data must first go through the state estimator before being used by the other programs.

The control in PSCC consists of the three following levels:

- Level 1: Instantaneous control of the turbine governor, which adjusts generation to balance changing load.
- Level 2: The ACG, also known as load frequency control (LFC), repeats the process every 2 to 6 seconds to keep frequency and net power interchange.

- Level 3: Economic Dispatch divides the load amongst the units such that the fuel cost is minimized at intervals of 5 to 10 minutes.

The PSCCs are also in charge of the main voltage control in the power system for:

- The generator bus voltage, regulated by excitation controls.
- The Static VAR Controllers (SVC), shunt capacitors, transformer taps, and other transmission voltage control devices.

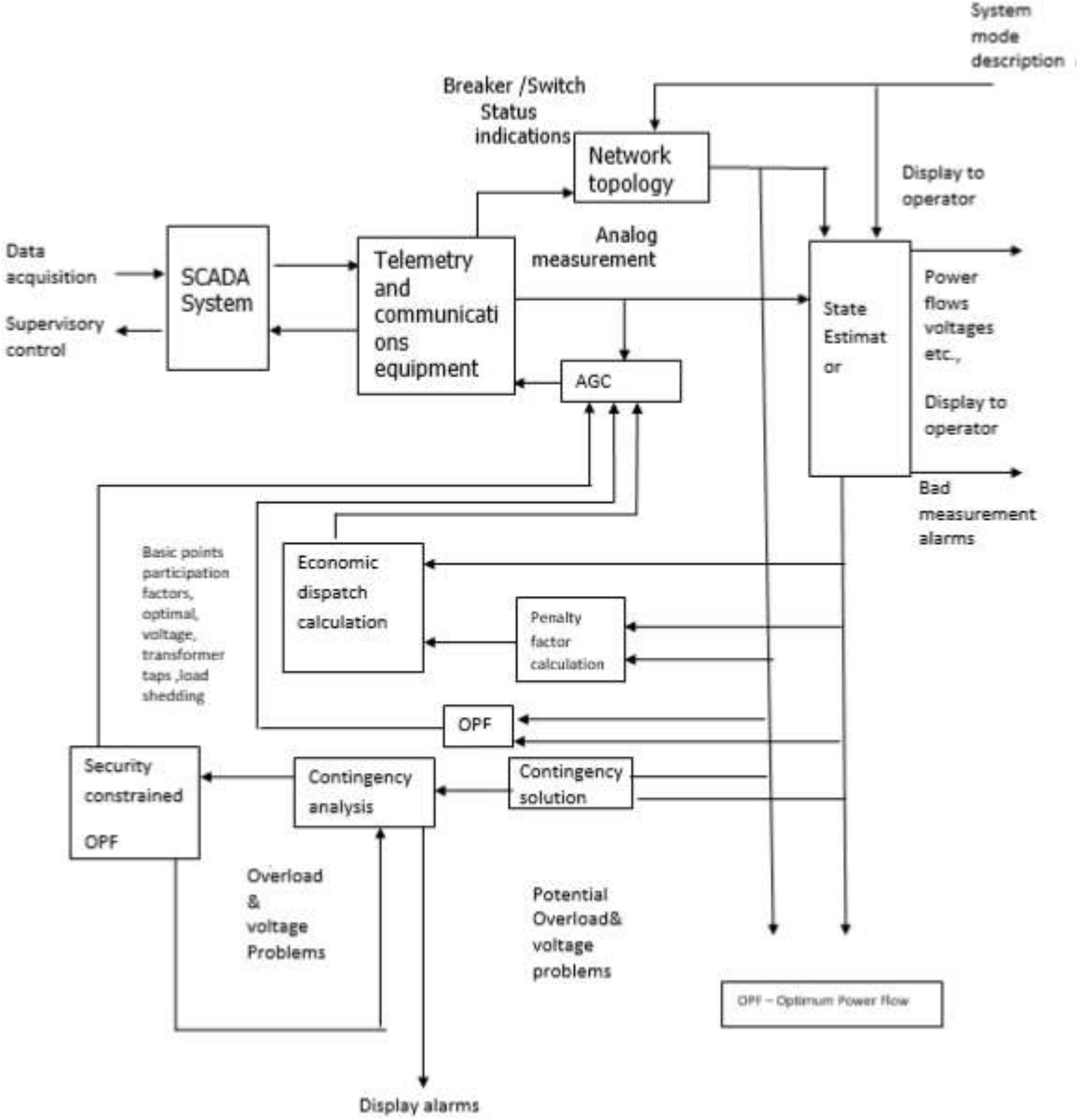

Fig. 1: Schematic diagram of the information flow between various computer-based tasks carried out in a PSCC.

2.2 Automatic Generation Control (AGC)

To adjust the generation against the load at the lowest possible cost, AGC consists of two main and a number of minor functions that run in real-time online. Load frequency control and economic dispatch are the two main tasks, and each is explained in detail below. Interchange scheduling, which starts and finishes scheduled interchanges, reserve monitoring, which ensures there is enough reserve on the system, and other comparable monitoring and recording operations are the minor functions.

2.3 Monitoring

An energy control center performs the task of coordinating the system components' responses during both routine operations and emergency situations. In typical circumstances, the digital computer is given the responsibility of repetitive control, while human operators do selected monitoring. The incoming stream of data is processed by the digital computer to look for anomalies, and the human operator is alerted by lights, buzzers, and monitor presentations. Digital computers frequently handle much lower-level or less serious incidents of exceeding normal boundaries. Normal control operations might be suspended if the digital computer detects a more serious problem. Many alerts may be found in emergency situations, such as the failure of a significant generator or excessive power demands placed on tie lines by a nearby utility. In these situations, the system may enter an emergency status.

2.4 Data Acquisition and Control

Data acquisition supplies the status and measurement data required to oversee the overall operations of computer control systems. The purpose of security control is to establish operating conditions by analyzing the effects of errors between the master station and remote terminal unit (RTU) of a Supervisory Control and Data Acquisition system (SCADA). To observe and manage power plants, the master station sends data to the RTU. At generating stations, transmission substations, and distribution substations, RTUs are placed. RTUs broadcast measurements and device status to the master station, and they also receive control instructions from the master station.

The steady-state reading can be simultaneously gathered from numerous instrument sites and preserved for later analysis using a computer-aided data-collecting technique. Voltage or current variations could be the outcome of the transient. It can be challenging to pinpoint the transient's origin in a real power system, where it may cause component failure. The transients can be lowered and analyzed using a data acquisition system.

2.5 Phasor Measurement Units (PMU) for Power Systems

A PMU is a device that determines the phase angle and magnitude of an electrical phasor quantity (such as current or voltage) in the electrical grid using a shared time source for synchronization. PMUs can rapidly reconstruct the phasor quantity—which consists of measurements of both an angle and a magnitude—using samples from a waveform. These time-synchronized data are essential because frequency imbalances can strain the grid's supply and demand, which could result in power outages.

PMUs can gauge the electrical frequency of the power grid. A typical PMU may report measurements up to 120 times per second with a very high temporal resolution.

Unlike traditional SCADA measurements, which generate a measurement every two to four seconds, engineers can now analyze dynamic grid events. As a result, PMUs give utilities improved monitoring and control capabilities, making them one of the most crucial measuring tools for the development of power systems. A PMU can be a separate device, or it can be integrated with another device, such as a protective relay, to perform the PMU function.

EMS and SCADA are examples of existing power grid technologies that can only provide a steady state picture of the power system with a high data flow delay. Due to technical issues synchronizing measurements from various locations, it is not possible to use SCADA to measure the phase angles of bus voltages of the power system network in real-time.

Measurements were made more slowly, and the operator only received a limited amount of information on the power system's dynamic behavior. By synchronizing voltage and current waveforms at separated places, PMUs helped to solve this issue. PMU outperforms SCADA in terms of performance, reliability, and speed.

A PMU is a device that uses voltage, current, and/or time synchronizing signals to estimate frequency, rate of change of frequency, and phasor. PMUs use Global Positioning System (GPS) signals to give real-time synchronized measurements in the power system with better than 1 ms synchronization precision. In power system substations, PMUs measure the time-stamped positive sequence voltages and currents of all the tracked buses and feeders. A suitable location is chosen for the collection of data from several substations, and a coherent image of the state power system is produced by lining up the time stamps of measurements.

The major applications of the PMUs are:

- Monitoring thermal overloads
- Analysis of disturbances
- Stability monitoring
- Restoration of the power system after a blackout
- State estimation

- Control in real time
- Adaptive protection

2.6 System Hardware Configuration

A small number of operators can keep an eye on the generating and high voltage transmission system thanks to the supervisory control and data acquisition systems. Electric utilities almost always use a redundant set of dual digital computers for the purposes of remote data acquisition control, energy management, and system security in accordance with the concepts of high reliability and fail-safe failures.

The online units, which are typically one computer, monitor and manage the power system. Off-line batch applications like load forecasting or hydro-thermal allocation might be running on the backup computer. A shared disk memory between the two computers is frequently updated by the online computer. The common disk's stored data is loaded into the online computer's memory in response to a failure over or switch-in status instruction.

The online computer's information has a maximum age of updating cycle. Using input-output microprocessors that have been configured to interact, as well as pre-process the analog information, check for limits, convert to another system of units, and other tasks, all peripheral equipment is connected to the computer. The central processing unit is not hampered by the microprocessors' ability to move data in and out of computer memory. These safeguards frequently result in a 99.8% or higher availability guarantee for all crucial hardware operations.

In addition to hardware, fresh digital code for the system's control can be created, tested, and put online on the backup computer. Most of the time, digital computers are used in fixed cycle operating mode with priority interrupts, which causes them to run a series of tasks on a recurring basis. The scan cycle for the most important functions is the quickest. The following categories are typically scanned every two seconds:

- Every status point, including the location of the switchgear, the loads and voltages in the substation, the tap positions of the transformers, and the capacitor banks.
- Schedules for interchanges and tie-line flow.
- Lines' capacity, operational restrictions, and generator loads and voltage.
- Telemetry verification to find errors and failures in the distant bidirectional communication links between the digital computer and remote equipment.

Every 4 seconds, the turbine generators are frequently instructed to operate at higher power levels, with load adjustments dependent on each unit's response capacity in MW/min. The computer, while running an economic dispatch program, adjusts the base power settings for each unit's reaction capabilities every 5 minutes on average.

3 Power System State Estimation

The system states produced from unsophisticated measurements in power systems are not precise enough to be used for complex system operations and online control due to the inherent flaws in metering devices and communication networks. This is why correct state estimation is a crucial feature in power systems. Based on a collection of real-time measurements, a state estimator (SE) establishes the state of the system. There are three kinds of real-time measurements that can be made within the framework of a PSCC:

- Examples of analog metrics are real and reactive power flows over transmission lines, real and reactive power injections, and bus voltage magnitudes.
- Switch and breaker state, as well as transformer LTC positions, are measured using logic.
- Predicted bus loads and production are examples of pseudo-measurements.

Telemetered readings of analog and logic are sent to the PSCC. The statistics may contain noise and errors. Data errors can be brought on by noisy communication systems, malfunctioning measuring and telemetry equipment, and delays in data transmission. A system's state is described by a set of variables that, at any given moment, contain all the data necessary for us to fully predict how the system will behave at time t. A practical decision is to choose a small number of variables, designating a small number of state variables that are adequate. It should be noted that the state variables may not always be easily available, quantifiable, or observable. The system model used is built on a nodal depiction, making the choice of the state variables simple.

The voltage magnitudes and angles are the state variables, while line impedances are assumed as known. This follows because, once the state values are known, all other values can be specified uniquely. State estimation is a mathematical procedure that generates a description of the power system by computing the best estimation of the state variables (bus voltages and angles) of the power system based on the incorrect data that was received.

Secondary quantities (like line flows) are easily derivable once state variables are approximated. The network configuration is established by the network topology module after processing the logic data. In addition to using data from the network parameters, the configuration of the network provided by the topology of the network, and occasionally pseudo measurements, the state estimator processes the collection of analog measurements to determine the system state. Since it is not feasible to measure all network parameters in-depth in the field, one-line diagrams and manufacturer data are used to calculate parameter values. This could then add another potential error source.

The fundamental power system state estimator's mathematical formulation assumes that the power system has static behavior. Assume a system with n state variables, represented by x_i where i=1,...,n. Suppose there are m measurements accessible. The state vector is x, and the measurement vector is indicated by the letter z. If the noise is v, then the relation between measurements and states denoted by h is given by:

$$z_i = h_i(x) + v_i \qquad (1a)$$

or:

$$z = h(x) + v \qquad (1b)$$

If h(x) is linearized, then:

$$z = Hx + v \qquad (2)$$

The measurement matrix, or H, is unaffected by the state factors.

The goal is to find the best estimation of x, denoted by $\hat{x}$. The weighted least squares (WLS) idea is the foundation of the most widely used method. The technique seeks to reduce the differences between the related equations and the measurements. To achieve this, the next optimization function must be minimized:

$$\min J(x) = \frac{1}{2}\left(z - h(x)\right)^T R^{-1}\left(z - h(x)\right) \qquad (3a)$$

Where R is a diagonal matrix that has the variances of the measurement error. (3a) can be rewritten as:

$$J(x) = \sum_1^m k_i (z_i - h_i(x))^2 \qquad (3b)$$

To have a minimum the following equation must be fulfilled:

$$\frac{\partial J(x)}{\partial x} = -H(x)^T R^{-1}[z - h(x)] = 0 \qquad (4)$$

Where H(x) is the Jacobean measurement matrix with m x n dimensions:

$$H(x) = \frac{\partial h(x)}{\partial x} \qquad (5)$$

After h(x) is linearized:

$$h(x + \Delta x) \cong h(x) + \Delta x \qquad (6)$$

The following obtained:

$$(H^T R^{-1} H)\Delta x = H^T R^{-1}[z - h(x)] \qquad (7)$$

$$x^{k+1} = x^k + \Delta x \qquad (8)$$

The best estimations are found by applying the equation below:

$$x_{k+1} = x_k + \left[H_k^T W H_k\right]^{-1} H_k^T W [z - h(x_k)] \qquad (9)$$

This means that a criterion of convergence decides when the iteration is halted, and the state variables are incrementally approximated to a value. The measurements are related to one another separately by the matrix W, also known as the weighting matrix. The selection of W components affects the outcomes. All measurements are of identical quality if W=I is chosen.

4 Assessment of Steady State Stability

The analysis of steady-state stability goes far beyond merely estimating the probability of instability as small, gradual changes in load near the maximal loadability limit. The steady-state stability analysis calculates the separation from a system state where voltages may collapse and units may lose synchronism, regardless of the underlying solution technique. This distance is measured using a straightforward indicator called the steady-state stability reserve. System-wide and for transmission corridors with stability restrictions, the evaluation is conducted.

4.1 Steady-State Stability (Power and Voltage Reserve Indicators)

The idea of steady-state stability reserve provides a very simple way to express "how far" the present, or actual, system state is from the "critical" state where even a small change in the operating parameters may result in steady-state instability. These are the two categories of stable reserve indicators:

$$stability\ reserve_{power} = \frac{P_{max} - P_{base\ case}}{P_{base\ case}} \cdot 100[\%] \quad (10)$$

$$stability\ reserve_{voltage} = \frac{V_{base\ case} - V_{critical}}{V_{base\ case}} \cdot 100[\%] \quad (11)$$

where:

$stability\ reserve_{power}$: determines the stable reserve's power capacity (in MW).

$\text{stability reserve}_{\text{voltage}}$: determines the voltage values for the stable reserve.

P_{max}: is the total power (in MW) of the system's utilization, including generation and imports.

$P_{\text{base case}}$: is the power (in MW) in the actual (base) case.

V_{critical}: is the average system voltage in the critical case.

$V_{\text{base case}}$: is the voltage in the base case.

Maximum MW network utilization, also known as maximum MW loadability, or the system operating conditions just before the state of voltage collapse is achieved by alternating steady-state stability calculations that determine whether the system is stable or unstable.

5 Dynamic Security Assessment (DSA)

The design of a DSA system enables the selection of various load-flow situations and the construction of individual contingencies for automatic evaluation. User-defined parameters are used to evaluate the contingencies. Figure 2 shows the procedure graphically. Several user-selectable load-flow scenarios are offered at the simulation level. The most serious scenarios can be chosen and calculated using the contingency builder. The software defines the security criteria that can be combined to create sets of standards characterizing the constraints of the system and are appropriate for each user's requirements. The DSA notifies and records the events that result in system limit breaches, such as unstable generators, voltages below 80%, angles between nodes greater than 40°, and so on.

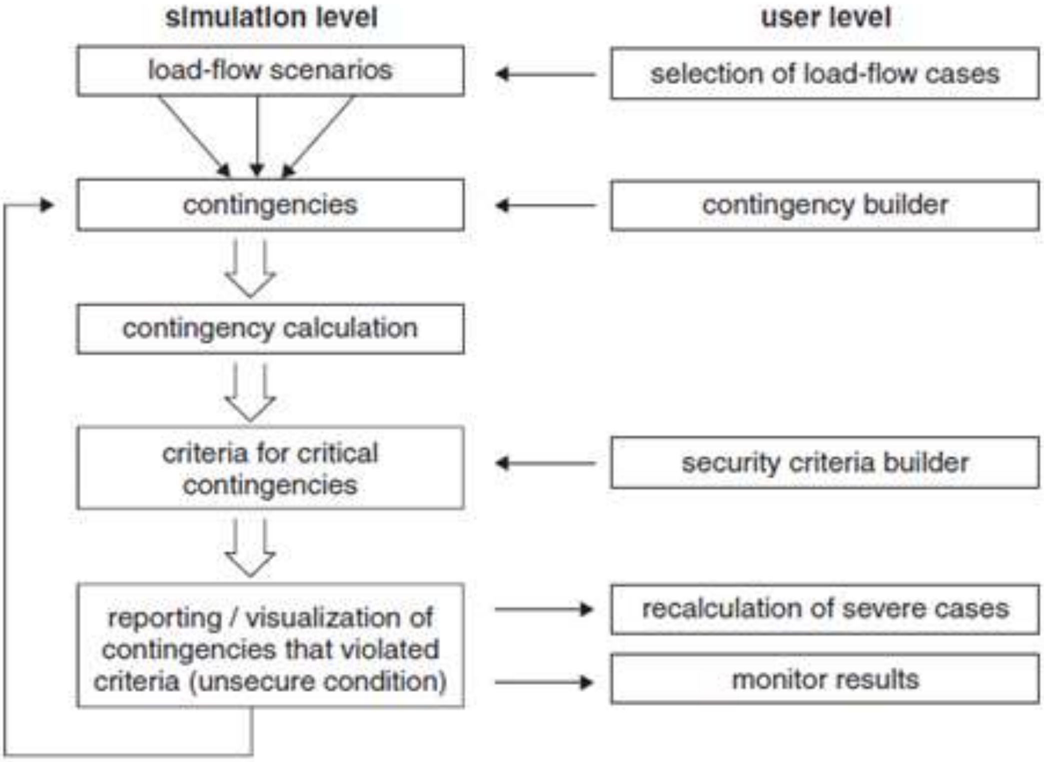

Fig. 2: The structure of the DSA system.

These scenarios are very simple to recalculate, and the analyst can see all the usual characteristics to get a clearer understanding. The operator can also keep track of the key contingencies concurrently. One of a DSA system's primary design criteria should be its capacity to:

- Simulate key elements of active switching or control equipment, such as capacitor banks and FACTS devices, along with their control mechanisms. These elements include lines, cables, transformers, and other inactive grid equipment.
- When simulating cascading faults, depict the essential protection's action.
- When simulating contingencies, use a straightforward method for building contingencies.

6 Restoration Plan

6.1 General Guides after a Blackout

The ability to restore an Electric Power System after any fault is critical to its operation. Many European Transmission System Operators (TSOs) have available online their restoration plans as the Belgian TSO (ELIA), [43], or the Irish TSO (EIRGRID), [44]. There have been plenty of research works on the restoration process after a blackout, [45], [46], [47]. The restoration process can be divided into three stages: start-up of generators, restoration of the transmission system, and restoration of supply to consumers (loads). After the start-up sequence of the generating units is determined, it is very important to find the shortest "path" to transfer the energy to the transmission network, so that we have an immediate energy supply to the network. In Table 1 the general guides for restoration after a blackout are shown.

Table 1. General guides for restoration after a blackout for the dispatchers of a PSCC

Actions	Tools
Communication	
Wind farm shutdown signal	
Communication of the National Control Center with all the Regional Control Centers, the Distribution System Operator (DSO), and TSOs of neighboring countries	Landlines, Mobiles Phones, or other communication systems each TSO has (e.g., power line carrier)
Status determination of Black Start (BS) and Non-Black (NBS) Start production units	
Communication with Black Start units – setting time for black start	Relevant information must be referred to the restoration plan of each regional control center
Communicating with non-Black Start units, determining their status and the critical time to restore power and restart time after power is restored.	
Priority of non- Black Start units for power supply	
Division of the transmission system into subsystems	
Division of the transmission system into subsystems	Use of the restoration plan as a guide and designing dividing lines in the network plan.
Clear demarcation of the subsystems	
Route selection from BS units to NBS units with priority	
Estimation of the transmission system status	Studies, reports, and information from the Energy Management System (EMS) that the TSO uses
Collaboration with the TSOs to ensure that the route has the required technical staff	
Subsystem electrification and load supply	
Subsystem electrification either using the bottom-up or the top-down method	
During the load supply, ensure that the frequency is high enough and the voltage drop that will occur with the connection will not create very low voltages	Priority of loads for reconnection in consultation with the DSO
Synchronization of subsystems	
Use synchronization points as defined in the restoration plan if possible.	Use of the restoration plan that each TSO has issued
Providing instructions to the operators during the synchronization process	
Completion of the restoration process	
Gradual System's restoration	EMS contingency analysis

Some important issues during a blackout are the following:

- The operators of black start power stations and the substations must be authorized so that, if no voltage is present, they will open all (external to the station) breakers.
- In thermal power plants, power to the auxiliary machinery must be restored within a short critical time to achieve a "warm restart".
- The TSO must declare its status (Normal, Alert, Emergency, or Blackout) to the EAS System, informing this way all the other TSOs of ENTSO-E.

The cooperation of TSOs, particularly those in proximity, is a crucial factor during the repair process. Typically, nearby TSOs must energize the interconnection power lines after a blackout during the top-down restoration process. The European Awareness System (EAS) is also a helpful instrument for communication between TSOs, signalizing the rise of emergency situations and also helping with system restoration. Distribution System Operators (DSOs) are typically encouraged to reduce loads before a major blackout and during the TSOs' attempt to prevent it. The DSO's "strategy" up to this point in the event of a blackout is to wait for TSO restoration and increase loads while it is happening. Cooperation between TSO, DSO, and governmental organizations like the Police and the Fire Brigade, should be guaranteed to reduce the restoration time in a blackout, particularly if it has been brought on by a natural catastrophe like flood, earthquake, fire, etc.

6.2 Activation Strategies after a Blackout

There are two central principles that guide the process of restoring the electricity system after a blackout:

Bottom-up: Using Black Start units and/or house load units with islanding capabilities, the affected areas are recovered by self-reactivating the area in chunks ready for resynchronization with another area.

Top-down: Using interconnection links to transfer energy from a safe system, a normally isolated system with a serious disruption is revived using external voltage sources. The interrupted TSO must vouch for its commitment to adhering to the limits of active and reactive power flows on the interconnection lines set forth in bilateral agreements.

The current practices across Europe are:

a. In the Baltic region, restoration plans are based on the top-down principle.
b. In continental Europe and the Nordic regions, both methodologies are used, considering the existing situation (availability of Black Start units and units in auxiliary feed mode within the TSO's area of responsibility, duration of the two principles, and the state of the voltage in the neighboring network).
c. In Great Britain, the restoration plans are based on the bottom-up principle.
d. In the Ireland / Northern Ireland region, once the Black Start units start-up, the non-Black Start target unit supply restoration routes will be activated and initial load restoration will be required to stabilize the restoration routes (balancing the production with the demand).

The TSO determines the load restoration steps required in terms of size and location and the relevant DSO load coordinator will implement them. Very good coordination between TSO and DSO is required, especially in the early stages of restoring stable operation and minimizing frequency and voltage deviations.

For example, in Figure 3 the geographical distribution of three separate subsystems (NW, NE, S), during restoration in the Belgian TSO (ELIA), using the bottom-up strategy is depicted, [43]. The restoration plan defines that in case of a blackout, 4 black start units will be used for the formation of these three separate regions.

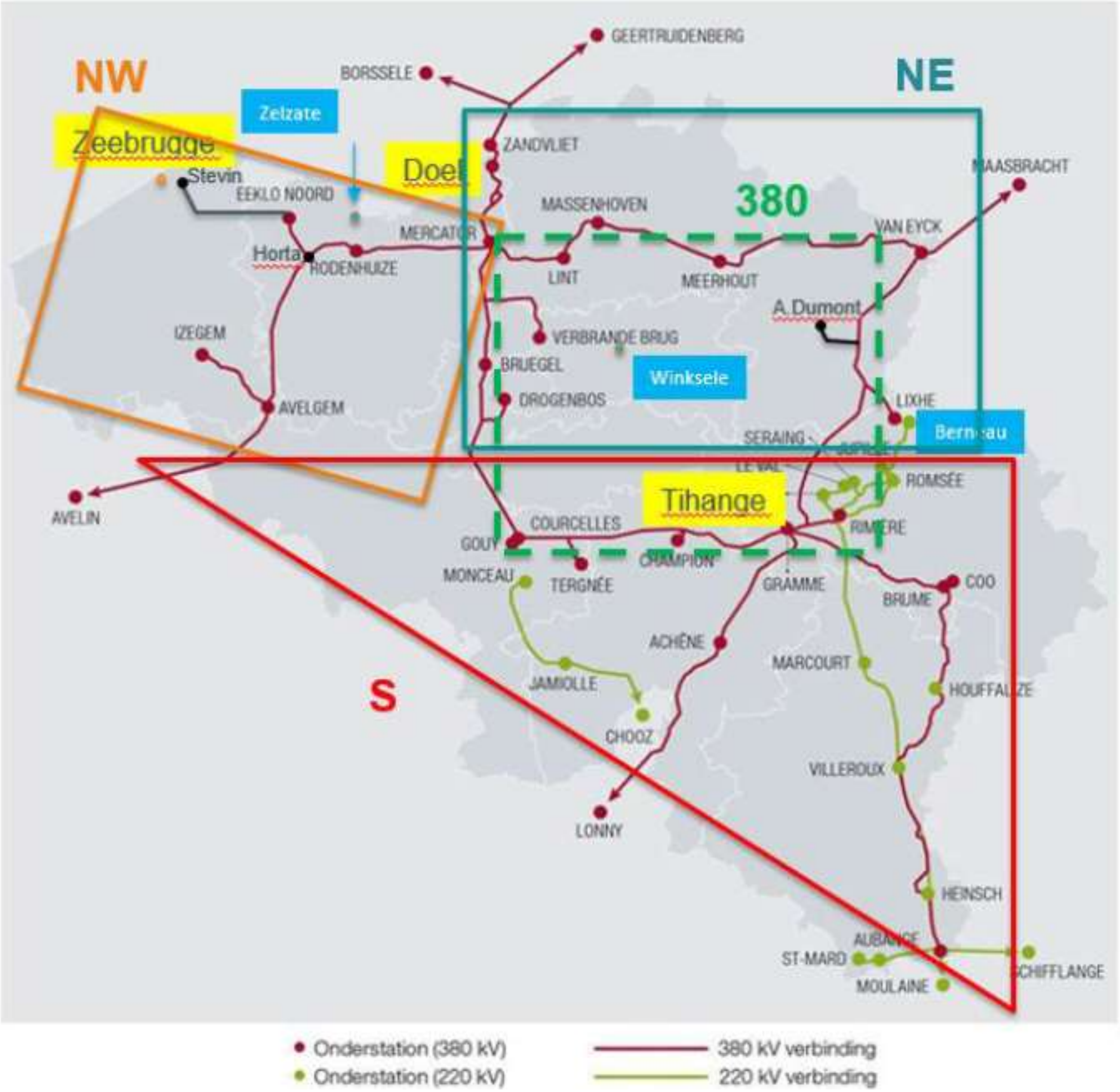

Fig. 3: Geographical distribution of 3 separate subsystems (NW, NE, S), during restoration in the Belgian TSO using the bottom-up strategy.

6.3 Factors that May Affect the Restoration Process

Although there is a restoration plan from every TSO, very often there are some unpredictable situations that may cause its modification during restoration, [46]. In [47], an estimation method of the probability of restoration or recovery time for electric power systems is proposed. Common problems that occur during a restoration process are:

- Generators that lose their auxiliary loads may not be able to remain in this state for long. In many stations, it is not possible to close the high voltage (HV) switch with a "dead busbar" so that a subsystem cannot be formed from a single generator.
- According to restoration guidelines, all substations must be isolated, which means that all circuit breakers must be opened. However, some high-voltage circuit breakers may not have opened in time.
- The mobile phone network will almost certainly be congested and may even collapse due to a national outage. A complete failure of all communication systems is extremely unlikely.

Satellite phones must be installed at multiple key locations, including all Black Start power units and all Control Centers. If these phones are the only available methods of communication, recovery time will be significantly longer.
- Some electrical components of the Transmission System (substations, power lines, etc.) may be unavailable as planned in the restoration plan. Uncontrollable parameters such as traffic chaos and extreme weather conditions can significantly delay the access of personnel to the substations or the control centers on the day of the incident.

7 Discussion

In this work, the role of a PSCC has been analytically presented. The monitoring and control of the grid through the PSCCs provide reliability because it enables the operation of the grid even closer to its limits. The PSCC is the “brain” of a power system. It detects the power system's condition, finds its state, plans its movement, and offers protection from exogenous events. However, the final decisions are taken by the personnel of the PSCC known as dispatchers. Dispatchers are electrical engineers, working in shifts to provide the system’s balance and are the ones who will face the great difficulty of a blackout. They should be technically educated, and well-trained because the importance of their job demands it.

This research work focuses also on the importance of the dispatcher in a possible blackout. The restoration plan as it was presented in section 6 will not be possible to be followed unless capable and well-trained dispatchers know what to do in such an event. Sometimes they have to unjust the restoration plan, something that requires skills. The software systems that a PSCC has are extremely important for the operation of a power system and cannot be done by humans. However, the restoration process following the bottom-up or top-down procedures needs dispatchers who will be able to adjust it to the current power system’s conditions.

8 Conclusions

The crucial role of PSCCs in the optimum operation of power systems and their significant role in power system restoration have been discussed in this work. However, they need improvements in their design and operation. Here are a few things to think about when designing control centers:

- Many control centers that are unable to communicate with one another cannot control a single interconnected grid. It must be simple to store and exchange data automatically and continuously without relying on operator-to-operator phone calls.
- The monitoring systems must be standardized, including the frequency of data collection, time stamping, alarming, visualization, etc., to allow dispatchers at various control centers located throughout the grid to interact effectively.
- More specificity is required in the control reliability requirements. The same ones, like voltage control, are less common even though this has been done for frequency control.
- The real-time data made accessible to operators and control centers across the grid should be chosen based on reliability requirements. The current argument over whether certain data belongs to generating firms as proprietary must end when the grid's dependability is harmed.

If the above suggestions are adopted the operation of the power systems via the control centers will be significantly improved and the very known effects of possible back out to the society and the economy will be minimized.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

The authors equally contributed in the present research, at all stages from the formulation of the problem to the final findings and solution.

Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself

No funding was received for conducting this study.

Conflict of Interest

The authors have no conflict of interest to declare that is relevant to the content of this article.