B&H Electrical Engineering, Volume 20, Issue 1, 2026
ISSN:2566-3143, eISSN:2566-3151, DOI: 10.2478/bhee-2026-0004

Original scientific paper

Submitted: April 17, 2025

Accepted: October 12, 2025

POWER SYSTEM RECOVERY STRATEGY AFTER A MAJOR BLACKOUT

Hamza Feza Carlak[1,3], Ergin Kayar[1,2]

Abstract: A plethora of factors have been identified as contributing to the current deficit in energy production and supply. These include power outages, transmission line overloads, discrepancies between energy production and demand, errors in load forecasting, meteorological phenomena, maintenance issues, cyber-attacks, and terrorist or criminal acts. The unpredictability in the production of renewable energy sources, aggravating the problem of consistently matching supply to demand in electricity grids. This article considers the possibility of a power outage over a large area of the interconnected electricity transmission system. It also presents how to prevent such a possibility, as well as the remedial actions to follow to prevent a catastrophic event such as a power outage. The safety criteria of the transmission system, the defense plans and the remedial actions that the system operator should prepare to prevent a major power outage are described. First, the major power outages that have occurred in recent years are presented and their causes are examined. In addition, it has been tried to find similarities between the past power cuts in Turkey and the state of the European electricity grid. A transmission failure simulation test environment has been developed to understand the characteristics of realistic transmission level disturbances propagated to the power system and the effects of such disturbances on the performance of conventional conservation and restoration technologies. By using both Black Start units and connection lines from neighboring system operators, it was ensured that restoration time was minimized by creating separate islands that would eventually be synchronized. In the study, a restoration strategy was presented. The proposed strategy has been tested and validated in the IEEE-39 bus system. The results proved the efficiency of the restoration strategy, as the total restoration time was sufficiently short depending on the complexity of each system, and critical loads were primarily fed.

Keywords: Blackout, Black Start, Dispatching, ENTSO-E, Restoration Plan, Interconnection system

INTRODUCTION

Power outages are attributable to a multitude of factors, including transmission line overloads, high demand levels with inadequate energy production, errors in load estimation, meteorological phenomena, maintenance issues, cyber-attacks, acts of terrorism or crime, and transmission failures [1]. In the most unfavorable circumstances, instabilities can frequently result in partial or complete power outages due to cascading failures, which present unparalleled challenges to the Transmission System Operator (TSO), Distribution System Operator (DSO), and plant operators [2-4]. The occurrence of these events necessitates the implementation of system restoration strategies, with the objective of ensuring the safest and fastest possible return to normal operating conditions. This is to minimize economic losses and impact on society [5]. In order to restore normal operation following a power outage, a BS procedure must be carried out, such as the restoration of a power plant or part of a power grid without reliance on external power sources [6]. The procedural goals are twofold: firstly, to reduce the restoration time, and secondly, to ensure the safe and rapid return of the power system to normal conditions. In pursuit of these objectives, a plethora of unstructured approaches, technologies, and object-oriented expert systems have been employed in the formulation of restoration schemes [7]. The risk of a large-scale blackout, or even a blackout affecting an entire country, remains a constant concern. Despite the interconnected nature of most European countries' power systems, and the existence of guidelines from the European Network of Transmission System Operators (ENTSO-E) to ensure the most reliable operation of the European grid, the possibility of a major disruption or, more critically, a complete blackout remains a constant threat [8]. In the event of a generator failure, the load will immediately exceed the production capacity, causing the frequency to drop. However, should the loss of generation remain within a manageable range, it is possible to maintain grid operation by increasing production or by shifting load shedding from the system's hot reserve capacity accessible from operating power plants. Conversely, in the event of a significant reduction in load, the system will have excess

This paper was submitted to the Conference of the South-East European Regional Council of CIGRE (SEERC 2025), held in Sarajevo, Bosnia and Herzegovina, on June 4–5, 2025.

[1] *Department of Electrical and Electronics Engineering, Akdeniz University, Turkey*
[2] *Department of Western Mediterranean Load Dispatch Directory, Turkish Electricity Transmission Corporation (TEİAŞ), Turkey*
[3] *Correspondence email: fezacarlak@akdeniz.edu.tr*

generation, thereby increasing the frequency. This will necessitate a reduction in production capacity to ensure the system returns to an acceptable frequency level [9]. A breakdown can be initiated by a few factors, including an overloaded line or transformer being out of service, a busbar fault, or a line fault with a non-working breaker. High-speed protection systems have been developed to allow faults to be located and rectified in a distinctive manner. Consequently, variables such as interruptions in transmission lines, relay failures, and equipment tripping due to overload can propagate the disturbance, amplifying its impact and resulting in a power outage [10]. The node contraction method was introduced to determine the importance of nodes [11]. A fuzzy chance-restricted model has been proposed to address the uncertainty surrounding working time and operational lines [12]. This model was solved using a hybrid fuzzy simulation approach that combines particle swarm optimization (PSO). In accordance with the requirements of the power system, a hierarchical collaborative optimization approach has been proposed [13]. The targets are defined as total power generation and network reconfiguration level. Power system restoration plans are graphically visualized to facilitate the estimation of restoration time and the planned critical route [14]. A novel approach has been developed for estimating recovery time, drawing upon machine learning techniques previously employed in restoration events [15]. A unique restoration technique, built on the A* algorithm, has been achieved with a focus on the rapid and reliable supply of consumers following a power outage [16]. This work seeks to integrate the restoration techniques previously referenced, with a view to establishing and combining skeletal networks on the islands where the BS units were initially restored, with the objective of facilitating the relaunch of non-black start (NBS) units. If these corrective actions prove unsuccessful in preventing the power outage event, it is imperative that each TSO has a restoration plan in place to swiftly and safely supply power to its consumers. The overarching objective of this study is to develop an efficient restoration strategy, given the inherent possibility of power outages. [17]. The restoration methods that have been developed after such an event focus on the strategy that should be followed by the dispatchers working in the control centers of the Transmission System Operator, rather than on the capabilities of the networks. This study proposes a restoration technique to increase distribution system resilience following a power outage, using distributed generation for the restoration of significant loads.

1. METHODS AND MODELS

1.1. Stability of the Power System

The stability of a power system is indicative of the principal conditions that can give rise to an emergency or power outage. The ability of the power system to maintain synchrony in the face of minor disruptions is addressed by rotor angle stability. The transient stability of the system is influenced by the initial operating state of the system and the magnitude of the outage. Frequency stability, defined as a power system's ability to sustain a consistent frequency following a substantial system failure that results in a considerable imbalance between generation and load, is another crucial aspect. The system's capacity to maintain or restore balance between production and load is contingent on its ability to do so without significant unintentional load loss. Constant frequency fluctuations can cause unit generators or loads to fail, which can lead to instability. Voltage stability, defined as the capacity of a power system to maintain constant voltages on all busbars following a breakdown caused by a given initial operating condition, is also a crucial factor. This is contingent upon the power system's capacity to maintain or restore equilibrium between load supply and demand. A gradual decrease or increase in the voltages of some busbars can cause instability. This instability can result in a loss of load within a specific area or the deactivation of transmission lines and other components by their protective mechanisms, leading to successive interruptions. Furthermore, due to these interruptions or operating conditions that exceed the field current limit, some generators may lose synchronization.

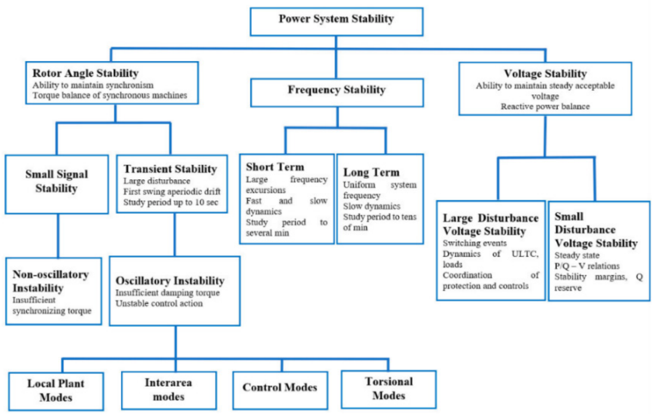


Figure 1: Stability classification of a power system [18]

Power System Situations

In the context of power systems, awareness of system status is of paramount importance. The various states of a power system are contingent on the size of the grid, the risk levels of frequency disturbance, and the actions required to limit the propagation of faults that may occur in the grid. The system's states can be categorised into four distinct categories, as outlined in [19]. The first state is designated as 'Normal Condition', which encompasses standard operating conditions. This is the operating state in which the system is within the limits of safe operation, in a stable state and after the occurrence of any emergency, considering the effect of the available corrective actions.

B&H Electrical Engineering, Volume 20, Issue 1, 2026
ISSN:2566-3143, eISSN:2566-3151, DOI: 10.2478/bhee-2026-0004

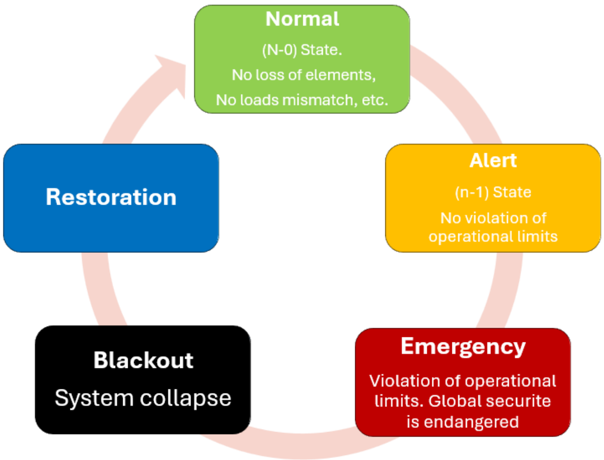


Figure 2: System statuses

The State of Restoration is defined as the status of the system in which all actions are directed towards the restoration of the transmission system and the maintenance of its safe operation following a power outage or emergency. The present chapter focuses on the challenges and current developments related to power system restoration. This includes a review of existing restoration strategies and regulations, with a focus on concepts and requirements issued by TSOs.

Blackout Analysis

The process that ultimately results in a blackout necessitates a sequence of complex actions. It has been demonstrated that the process may be subdivided into four phases of gradual events which ultimately result in a blackout [20]. The initial period preceding a substantial power outage is designated as the first-step prerequisite. The subsequent triggering of events that result in the destabilisation of the power grid are the causative factors for the blackout. This initial disruption then propagates through the grid via a sequence of actions that can extend from seconds to hours. Typically, the gradual steady state can be divided into the second step (slow) and the third step (fast). The assessment of unserviced loads, loss of power generation, and the number of people affected can be conducted following the culmination of the final stage of the blackout. Subsequent to this, the system transitions into the fourth phase, which is the restoration phase. This phase can take a duration ranging from minutes to several days.

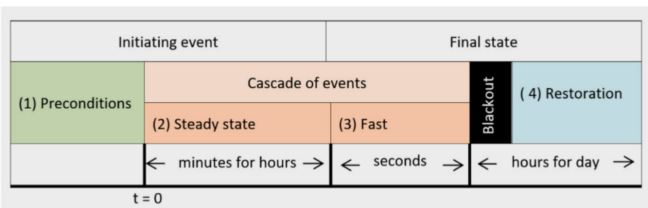


Figure 3: Progression of a Blackout

Restoration Strategies

In consequence of repeated failures in power transmission networks, even a robust energy system can become susceptible and incur a catastrophic long-term power outage. In order to prevent such successive failures, the implementation of real-time detection and communication, fault analysis and self-healing control is proposed as a wide area defense system. The restoration of power systems constitutes a pivotal element of the self-healing control mechanisms within the overarching defense system. The system restoration procedure involves the assessment of system status, the optimization of production capacities, and the acceleration of load pickup. The restoration problem is characterized by a multitude of practical considerations, which hinders its formulation as a single optimization problem. Furthermore, these optimization problems are inherently combinatorial in nature. To illustrate this point, consider the example of a dynamic programming problem, which must be solved to determine the most efficient manner in which to restart production units.

Power System Restoration

A general procedure for power system restoration consists of three stages: preparation, system restoration, and load restoration. The primary distinction between the preparatory phase and the subsequent stages is the temporal nature of the preparatory phase, where the urgency of measures necessitates immediate attention. During the preparation and system restoration phases, load control is employed to maintain system stability, while during the load restoration phase, load restoration is the primary objective [21]. The strategies employed by system operators for power system restoration can be categorized as either bottom-up or top-down [22, 23].

Bottom-up: The re-energization of the system is carried out by production units with black start capability within the control area of the respective system operator.

Top-down: This restoration strategy relies solely on HVDC or HVAC interconnects, and therefore energy from neighboring TSOs.

Test System

The validity of the proposed methodology has been demonstrated in the modified IEEE-39 bus system. The system model was developed using Dig-SILENT Power Factory software (Appendix A). System data has been derived from realistic values. To further evaluate system performance during over-frequency and low-frequency situations, an over-frequency condition and a low-frequency condition are designed for each system. In situations involving extreme frequencies, the system frequency response is derived from the loss of the largest load. Conversely, the system frequency response results in low-frequency situations are based on the activation of the largest generator. The system under consideration contains 10 production units, with a total production capacity of 14,535 MW of nominal active power and 9,008 MW of nominal reactive power. The total load, in terms of active power, is 6097 MW, while the load, in terms of reactive power, is 1409 MVar. The presence of four black start units in buses 33, 34, 36 and 30 is also assumed. The criterion of dividing the test system into islands is employed, with the result that the system is divided into three islands (Appendix B).

2. SIMULATION RESULTS

The establishment of a reliable black start (BS) strategy is a distinctive feature of the power grid. A conventional power system restoration plan comprises three distinct phases: preparation, system restoration, and load restoration [24, 25]. At the initial stage, the system state is analyzed and a strategy is developed for the system BS. In the subsequent stage, generators capable of black start functionality are initiated, with the subsequent energization of transmission lines and the activation of other NBS-starting generators. The final stage of the process involves the rapid restoration of system load [26]. In the event of a power outage, a series of steps must be taken to restore normal operating conditions in the power system [27, 28]. The creation of a restoration plan necessitates a technical feasibility assessment under both stationary and temporary operating conditions [29]. The technical constraints that must be addressed are listed as follows: active power balance and frequency control, reactive power balance and surge control, self-excitation, cold loading, system stability, protective systems, load control, and dividing the system into islands. In order to restore the system as quickly as possible, especially in the case of a collective system, it is necessary to divide the system into islands [30]. Each island must possess sufficient black start capability, enough crank paths to operate non-black start units or to pick up loads, and the ability to generate and match the load within set frequency limits. Each island must have adequate voltage controls in place to maintain the proper voltage profile. It is also vital that all ports belonging to subsystems have the capacity to synchronize with adjacent subsystems, and that all islands share information with other islands.

The proposed restoration approach is validated using a modified IEEE 39 bus system. The model system is intended to represent interconnected island grids following a significant power outage. The system comprises ten generators, of which three are designated as BS units. The objective of the black start process is to deliver power to all loads as effectively as possible. The distinguishing feature of this configuration is the collective facilitation of black start by multiple units. The application of this configuration is found in complex power networks that include both BS and NBS areas. The significance of BS units in optimally managing energy within their respective areas, adapting to both standard and emergency operational scenarios, cannot be overstated. The energy management system is focused on the interaction between the BS capacity within these island networks and the hierarchical load sequence. In the event of a power outage, critical loads on the grid are prioritized for powering by generators with BS specifications. Following this, attention has been paid to both dedicated power sources and geographical proximity in order to facilitate support to adjacent areas that do not have such capabilities. The proposed management system is simulated to increase system inertia during BS procedures, maximize the effectiveness of load shedding strategies, and optimize the integration of renewable energy sources. The hierarchical energy management system signifies a substantial advancement in this domain by addressing both distribution and transmission levels, thereby ensuring efficient energy management and grid stability in both normal and emergency scenarios. In scenarios where there is a loss of power, the primary focus of the BS is to ensure the provision of power to its critical loads. Once stability has been achieved and excess power is available, these areas then look to support the NBS in need. The re-energization of the system is performed by generation units with Black Start capability within the control area of the respective system operator. The configuration of a transmission network is implemented in phases to facilitate the provision of crank power. Subsequent to this, non-Black Start units near the load are then restored. The strategy is implemented in a phased manner, wherein the transmission grid is initially re-energized to aggregate Black Start power. Subsequently, power is then supplied to non-Black Start units. The sequence of actions involved in this process is as follows: the initiation of Black Start units, the energization of the transmission grid, and the subsequent energization of non-Black Start units. The problem is formulated with the objective of maximizing the number of critical loads weighted according to their priority for the shortest time after the post-failure topology is selected, considering power flow, uptime, operation and connection constraints. The methodology is founded on the categorization of loads into two distinct groups: non-critical and critical. The voltage stability index of the loads is also factored into the assessment. During the restoration process, it is imperative to maintain the system frequency within the permissible limits stipulated by turbine resonance, system stability, and protection settings. This is achieved by gradually increasing the load, ensuring that the inertia and response of the restored and synchronized system can accommodate it. In order to restore the system as expeditiously as possible, especially in the case of a batch system, it is necessary to divide the system into islands. Each island must possess adequate Black Start capability, and NBS units must have sufficient starting paths to crank or take loads. The restoration strategy is centred on the initialization of Black Start units, the cranking and parallelization of non-Black

Start units, the restoration of islands, and subsequent synchronization of islands. A hierarchical structure is employed in the power system domains to facilitate the efficient management of energy and ensure the maintenance of overall grid stability, particularly in normal scenarios and during emergency situations. The domains are categorised according to their BS capabilities. The design of different loads is intended to maintain the simplicity of the system while representing a hierarchical order according to their importance. In this structure, the first load is designated as the most critical, with subsequent loads representing less critical loads. Furthermore, the loads are also categorised as less critical and least critical in order to optimize power dispatch through the application of binary variables. This approach is organised to guarantee customized energy allocation with a focus on prioritization of power dispatch based on load criticality. During blackout scenarios, BSAs primarily focus on providing power to their critical loads. The objective is to ascertain the optimal distribution of power from BSAs to NBSAs, ensuring that the distribution is carried out in a manner that is both efficient and effective. As loads are gradually reinstated, power generation is progressively augmented. This sequence continues until all loads in the area are reconnected. It is at this juncture that the generator is deemed to have successfully initiated operation and transitions to its standard operating trajectory. In the BS scenarios, the baseline information from both the BSA and the NBSA is predetermined. From the NBSA, information is received about the starting power required for each genset, including genset characteristics such as starting times and minimum and maximum critical times. This information is of significance in that it is determined at the point of decision-making to eliminate low priority loads in order to preserve power for BS operations, albeit as a final recourse when available power is inadequate. Subsequent to the compilation of this information, the determination of the optimal route for the connection of the power transmission paths is made, with network resistance being considered in order to minimize the total path losses. In this regard, shorter routes with lower values of network resistance are preferred to longer ones. The most efficient path from the BSA to each NBSA was determined. The impedance of the transmission lines was given priority and utilized to ascertain the optimal path. This approach ensured that the selected path not only represented the shortest route but also minimised the impedance across the network. Consequently, the distribution factor was found to increase the prioritization of areas in closer proximity to the activated generators, thereby enabling them to receive power more expeditiously. This, in turn, contributes to enhanced grid stability and reduced transmission losses. The subsequent step involved the creation of a pre-generator starting sequence, which was achieved by ranking the generators according to their readiness and critical timing constraints. Generators with shorter starting times are prioritized, followed by those with immediate critical timing needs. The power balance constraint is another critical component in ensuring that the total power generated, including adjustments for non-critical and priority loads, matches the requirements for BS operation. This constraint is instrumental in regulating voltage levels and power flow within the grid, thereby ensuring that the voltage at any busbar remains within predefined limits and that the power delivered along any line does not exceed its capacity. These constraints are vital in preventing overloads and ensuring the reliable operation of the grid during restoration. The array is comprised of ten generators, four BS units and six NBS units. Each island is equipped with at least one BS unit, and the data for these is presented in Table I. The energy management system and the optimal network framework for each island are shown in solid lines (see Annex B). The restoration sequence and related restoration methods are summarised in Table II. Initially, the priority load is energised. The loads are then connected in a staggered manner to avoid problems such as voltage or frequency drops. The restoration of the loads on each bus is performed with minimum time expenditure. The restoration time is minimized by an optimal generator start sequence, an optimal transmission path search and resynchronization of the three islands. The Black Start restoration process is intricate, and consequently, the achievement of a Restoration Time is contingent on a multitude of factors, including resource availability and technical and communication elements that proceed in accordance with the plan for the Transmission Operator to physically manage the power islands. Turkey has adopted a planning assumption for the Restoration Period in accordance with its interconnected network; this means achieving an average Restoration Time of 24 hours to restore 60% of national demand, ensuring that this can be supplied economically and efficiently.

Table I: Data generators the IEEE-39 bus and its classification

Name	TerminalBusbar	Bus Type	Active Power (MW)	Reactive Power (MVar)	BS Unit
G 01	Bus 39	PV	1000,0	88,3	NO
G 02	Bus 31	SL	520,8	198,3	NO
G 03	Bus 32	PV	650,0	205,1	NO
G 04	Bus 33	PV	632,0	109,9	YES
G 05	Bus 34	PV	508,0	165,8	YES
G 06	Bus 35	PV	650,0	212,4	NO
G 07	Bus 36	PV	560,0	101,2	YES
G 08	Bus 37	PV	540,0	0,4	NO
G 09	Bus 38	PV	830,0	22,8	NO
G 10	Bus 30	PV	250,0	146,2	YES

Table II: Cranking paths from BS unit to NBS unit or Load

Island	BS Unit	NBS Unit	Critical Loads	Cranking Path Restored (Bus No)
Island 1	G 10	G 08	Load 26	30→ 2→ 25→ 37→ 26
			Load 3	2→ 3
			Load 8	3→ 18→ 17→ 27→ 26
Island 2	G 07	G 06	Load 23	36→ 23→ 22→ 35
		G 09	Load 24	23→ 24
Island 3	G 04	G 02	Load 16	33*34→ 19→ 16
	G 05	G 03	Load 15	16→ 15
			Load 12	15→14→ 13→ 12

The Probable Restoration Time is determined by employing a probabilistic model, incorporating multiple input variables. The creation of restoration time distributions is undertaken in a series of scenarios that attempt to reflect the severity of events that may occur. While acknowledging the inevitability of regional variations during this Restoration Period, the objective is to establish a broadly consistent restoration rate that reflects the regional nature of civil contingency planning. During the designated Restoration Period, demand will undergo a gradual restoration process through the establishment of a provisional transmission network. This approach aims to strike a balance between achieving a realistic level of grid energization and ensuring the sustained delivery of an economical level of service. The proposed energy management system employs a multi-level control strategy throughout the power system. The hierarchical structure of the system is designed to facilitate the efficient management of energy within power system areas, thereby ensuring the maintenance of grid stability, both in normal scenarios and during emergency situations. The system employs a classification system based on the BS capabilities of the islands. The present approach signifies an augmentation of the islands of power; however, the objective is to establish the skeletal version, designated the skeletal network. This approach offers the advantage of facilitating the earlier extension of ancillary materials to non-Black Start providers. This improves restoration, as the sooner these providers can start, the sooner they can contribute to the restoration of national demand and the remaining Transmission network.

3. CONCLUSION

A novel hierarchical energy management system has been developed, with the objective of enhancing black start capabilities and normal operations across transmission networks. The study's key findings and conclusions underscore the efficacy of the proposed system in optimizing load shedding, system inertia, and renewable energy utilization during black start events. The validity of the proposed strategy was verified through the utilization of a modified IEEE 39 bus system. The energy method has the potential to be applied to other radial distribution networks and tested in a real system to ascertain its efficacy in real-world scenarios. The coordination between interconnected transmission controllers effectively managed the complex interactions between the BS-enabled and NBS domains. The restoration of critical loads was facilitated by BSs within the island prior to the energization of neighboring areas. This comprehensive framework represents a significant advance in energy management systems. It is argued that this framework successfully addresses the key challenges of maintaining grid reliability and resilience. Furthermore, it will facilitate the large-scale integration of renewable energy sources, thereby enabling the transition to a more sustainable energy future. In the future, the generation mix that serves interconnected transmission is likely to look very different from today as more conventional BS (rotating mass power plants) close on the grid. These closures can be replaced by renewable and stored energy sources (RES, GES, BESS, etc.). Consequently, Black Start service providers may be required to deliver adequate Black Start services in the future.

REFERENCES

[1] Pourbeik, P.; Kundur, P.S.; Taylor, C.W. The anatomy of a power grid blackout—Root causes and dynamics of recent major blackouts. IEEE Power Energy Mag. 2006, 4, 22–29.

[2] Eremia Mircea and Shahidehpour Mohammad, "HANDBOOK OF ELECTRICAL POWER SYSTEM DYNAMICS", Tech. Rep., 2013.

[3] G. Fotis, V. Vita, and T. I. Maris, "Risks in the European Transmission System and a Novel Restoration Strategy for a Power System after a Major Blackout", Applied Sciences (Switzerland), vol. 13, no. 1, Jan. 2023.

[4] Stankovski Andrej, Gjorgiev Blazhe, Locher Leon, and Sansavini Giovanni, "Power Blackouts Europe: Analyses, key insights, and recommendations from empirical evidence", 2023.

[5] S Almeida De Graaff, "Power system restoration-World practices & future trends Country Approach Blackstart: Top-down Blackstart: Bottom-up", Tech. Rep., 2019.

[6] Pagnani Daniela, "Design and Integration of Black-Start Service Provision by Off- shore Wind Farms: To Assure Resilience in 100%-Renewable-based Future Power Systems", Ph.D. dissertation, Aalborg University, 2023.

[7] Adibi, M.M. Power System Restoration: Methodologies and Implementation Strategies, 1st ed.; Wiley-IEEE Press: Hoboken, NJ, USA, 2000.

[8] European Network of Transmission System Operators for Electricity (ENTSO-E). P8—Policy 1-8: Operational Training. Available online: https://gordoncheng.files.wordpress.com/2010/08/policy_8_finale8aabfe5baa6e9818be8bd89e8a893e7b7b4.pdf

[9] Weedy, B.M.; Cory, B.J.; Jenkins, N.; Ekanayake, J.B.; Strbac, G. Electric Power Systems, 5th ed.; Wiley: Hoboken, NJ, USA, 2012.

[10] ENTSO-E. Draft Network Code for Operational Security. 2012. Available online: https://eepublicdownloads.entsoe.eu/cleanocuments/pre2015/consultations/Network_Code_OS/120817-AS-NC_OS-Draft_Network_Code.pdf

[11] Liu, Y.; Gu, X.P. Skeleton-network reconfiguration based on topological characteristics of scale-free networks and discrete particle swarm optimization. IEEE Trans. Power Syst. 2007, 22, 1267–1274

[12] Zhang, X.L.; Liang, H.P.; Zhu, T.; Zhao, C.; Li, W.; Gu, X. Optimization of power network reconfiguration based on fuzzy chance constrained programming. Autom. Electr. Power Syst. 2015, 39, 68–74.

[13] Cao, X.; Wang, H.T.; Liu, Y.T. A hierarchical collaborative optimization method for transmission network restoration. Proc. CSEE 2015, 35, 4906–4917.

[14] Mota, A.A.; Mota, M.T.M.; Morelato, A. Visualization of power system restoration plans using CPM/PERT graphs. IEEE Trans. Power Syst. 2007, 22, 1322–1329.

[15] Duffey, R.B.; Ha, T. The probability and timing of power system restoration. IEEE Trans. Power Syst. 2013,

[16] Fotis, G.; Vita, V.; Maris, T.I. Risks in the European Transmission System and a Novel Restoration Strategy for a Power System after a Major Blackout. Appl. Sci. 2023, 13, 83

[17] Henderson, M.; Rappold, E.; Feltes, J.; Grande-Moran, C.; Durbak, D.; Bileya, O. Addressing restoration issues for the ISO new England system. In Proceedings of the Power and Energy Society General Meeting, San Diego, CA, USA, 22–26 July 2012.

[18] Kundur, P.; Paserba, J.; Ajjarapu, V.; Andersson, G.; Bose, A.; Canizares, C.; Hatziargyriou, N.; Hill, D.; Stankovic, A.; Taylor, C.; et al. Definition and classification of power system stability IEEE/CIGRE joint task force on stability terms and definitions. IEEE Trans. Power Syst. 2004, 19, 1387–1401.

[19] European Network of Transmission System Operators for Electricity (ENTSO-E). P1-P8—Policy 1-8: Operational Security, 2022.

[20] Velay, M.; Vinyals, M.; Besanger, Y.; Retiere, N. An analysis of large-scale transmission power blackouts from 2005 to 2016. In Proceedings of the 53rd International Universities Power Engineering Conference (UPEC), Glasgow, UK, 4–7 September 2018.

[21] M. M. Adibi and L. H. Fink, “Overcoming restoration challenges associated with major power system disturbances Restoration from cascading failures,” Power and Energy Magazine, IEEE, vol.4, no.5, pp. 68-77, 2006.

[22] ENTSO-E, “P5-Policy 5: Emergency Operations Document Control Chapters”, Tech. Rep., 2017.

[23] B. Badrzadeh, Power system restoration accounting for a rapidly changing power system and generation mix Power system operation and control C2 TECHNICAL BROCHURES. 2023.

[24] L. H. Fink, K.-L. Liou, and C.-C. Liu, “From generic restoration actions to specific restoration strategies,” IEEE Trans. Power Syst., vol.10, no.2, pp. 745-752, 1995.

[25] X. Chen, W. Wu, B. Zhang, and C. Lin, “Data-driven DG capacity assessment method for active distribution networks,” IEEE Trans. Power Syst., vol. 32, no. 5, pp. 3946–3957, Sep. 2017.

[26] R. Li et al., “Power supply interruption cost of important power consumers in distribution network and its emergency management,” (In Chinese), Power System Technol., vol. 35, no. 10, pp. 170–176, Oct. 2011.

[27] National Grid ESO, “NGESO Black Start from Non-Traditional Generation Technolo-gies”, Tech. Rep., 2019.

[28] M. Mirzadeh, R. Strunk, S. Matter, I. Bekker, M. Munderloh, T. Erckrath, L. Hofmann, and A. Mertens, “A rule-based concept for a bottom-up multi-master black start of an inverter- dominated low-voltage cell,” in 13th IEEE International Symposium on Power Electronics for Distributed Generation Systems (PEDG), 2022, pp. 1–6.

[29] Majchrzak, D.; Michalski, K.; Reginia-Zacharski, J. Readiness of the Polish Crisis Management System to Respond to Long-Term, Large-Scale Power Shortages and Failures (Blackouts). Energies 2021, 14, 8286.

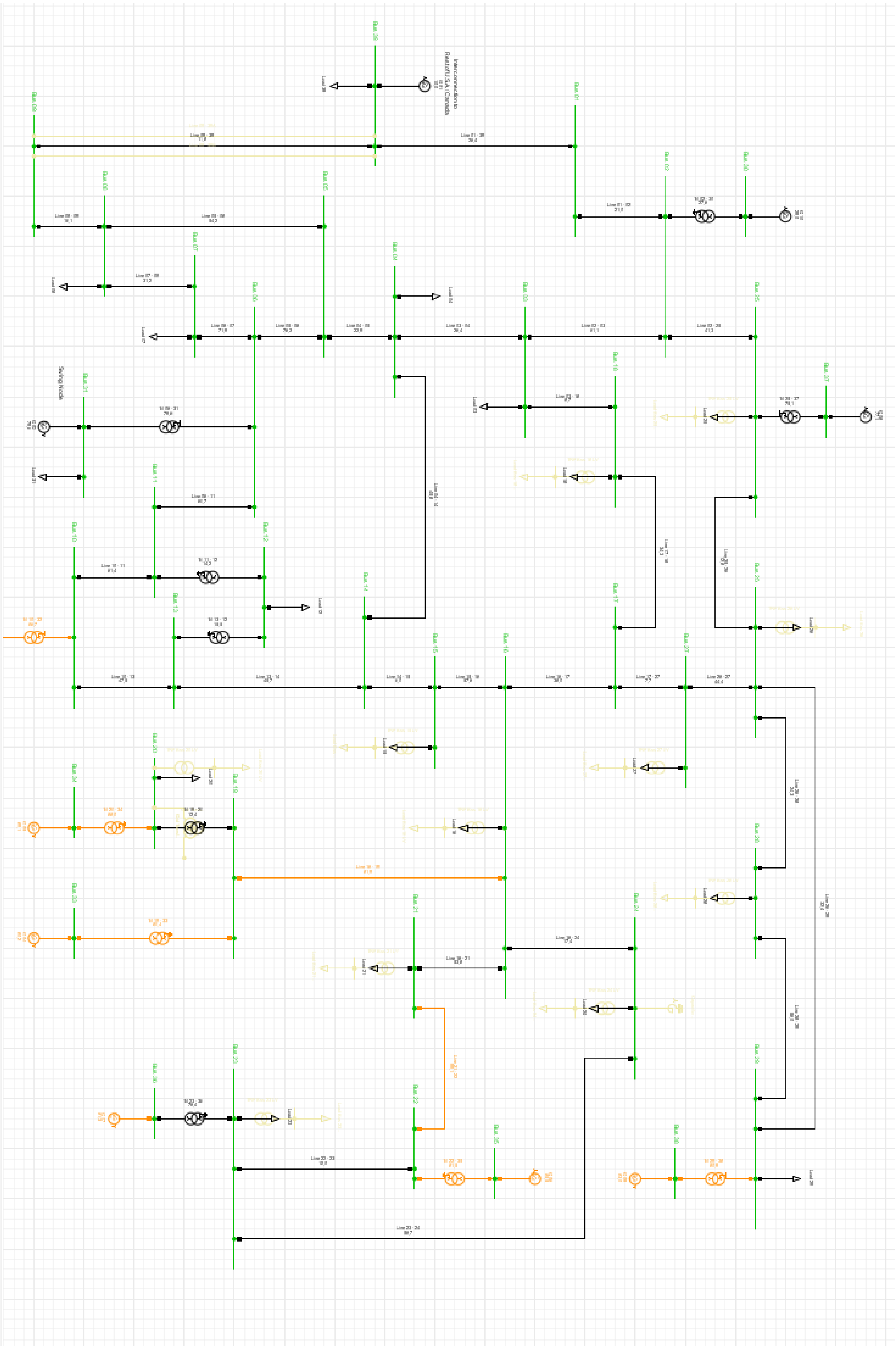
[30] European Network of Transmission System Operators for Electricity (ENTSO-E). Report on Blackout in Turkey on 31st March 2015

BIOGRAPHY

Hamza Feza Carlak received a B.Sc. in Electrical Engineering from Istanbul Technical University in 2000 and an integrated Ph.D. in Electrical and Electronic Engineering from Middle East Technical University in 2012. From 2003 to 2013, he was a research assistant at Middle East Technical University. Since 2017, he has been working as an associate professor in the Electrical and Electronics Engineering Department of Akdeniz University, where he has authored more than 80 papers and invented a medical imaging modality for which he obtained two international patents. His research interests are focused on power systems, medical imaging, image processing, renewable energy, and artificial neural network algorithms.

Ergin Kayar He received his B.S. degree in electrical and electronics engineering from Akdeniz University, Antalya, in 2017, and he is pursuing his Ph.D. degree at Akdeniz University, Department of Electrical and Electronics Engineering. He has been working at Turkey Electrical Communication Corporation (TEIAS) as an electrical engineer for 14 years. His research interests include power systems, renewable energy and power transmission systems.

APPENDIX A



ISSN:2566-3143, eISSN:2566-3151, DOI: 10.2478/bhee-2026-0004

APPENDIX B