BLACKOUT – KEY ASPECTS FOR GRID RESTORATION

Robert SCHMARANZ
Josef POLSTER
Stephan BRANDL
KELAG Netz GmbH - Austria
robert.schmaranz@kelagnetz.at
josef.polster@kelagnetz.at
stephan.brandl@kelagnetz.at

Herwig RENNER
Michael WEIXELBRAUN
Klaus KÖCK
Graz University of Technology - Austria
herwig.renner@tugraz.at
michael.weixelbraun@tugraz.at
klaus.koeck@tugraz.at

Michael MARKETZ
KELAG - Austria
michael.marketz@kelag.at

ABSTRACT

Recently occurred critical system states have triggered a broad discussion between Distribution System Operators (DSO) and Transmission System Operators (TSO) about the actuality and validity of grid restoration plans all across ENTSO-E. Generally being in the responsibility of the TSOs, the role of DSOs in the restoration concept in case of islanded grid restoration is not yet clearly defined and has been a topic in many discussions. Beside the organizational aspects regarding grid restoration, various technical requirements have to be considered. This paper highlights the key aspects of well-known as well as newly arisen topics. Furthermore, to guarantee a successful grid restoration, a 3-step approach is introduced. It contains islanded grid operation tests, the development of an accurate and reliable simulation model and the simulator-based training of the operators.

INTRODUCTION

The liberalized energy market and the growing contribution of energy from renewable resources have led to an increasing volatility of national and international load flow. Due to operation nearer to system limits, the risk of blackouts over the last years in the ENTSO-E grid has considerably increased.

Grid operators have the responsibility to investigate and, if possible, implement grid restoration plans. Therefore this topic is nowadays an important issue for TSOs, DSOs and power plant operators. The grid restoration plans have to be discussed with all stakeholders and trained as well as tested on a regular basis. Major aim of all islanded grid restoration plans is, considering the central significance of electricity in our society, the prompt, coordinated and stable reconnection of customer loads in the affected grid areas. Of central concern is thereby the communication among responsible stakeholders and the effective utilization of capable facilities, in particular units with black-start capability. Other important key variables are not yet considered thoroughly, e.g. the prevailing load characteristic in the event of a grid restoration (cold load pick-up) or the impact of dispersed generation during the restoration process.

The difficulty for the grid operators is to test the grid restoration plan under realistic conditions, especially with feasible load characteristics. KELAG Netz, an Austrian DSO, successfully provided islanded grid restoration tests in 2005, 2009, 2010 and 2011 in collaboration with power plant operators, the Austrian TSO and Graz University of Technology [1]. The first critical steps of the grid restoration plan have been practically exercised by switching pumps of a pump storage power plant to a designated generator configuration in an islanded part of the regional 110-kV-grid. With adequate measurements as a reference (including electric quantities as well as governor signals), the adjustment of a comprehensive dynamic simulation model was carried out. This model was further used to simulate critical sequences of the grid restoration plan assuming real consumer characteristics.

In a next step, a simulator-training of the operators – with special focus on the communication between DSO, TSO and the power plant facilities – was implemented to complete the requirements for a successful grid restoration.

RESPONSIBILITIES AND STRATEGIES

Regulatory Framework

Currently, the operational principles and rules and therefore the topic grid security and restoration are summarized in the UCTE Operation Handbook. The details for grid restoration are given in the Policy 5 “Emergency Operations”, describing the awareness of system states, the system defence plan and the system restoration.

The Third Package of directives and regulation from the European Commission introduces a new system for the establishment of binding European-wide network rules – the Network Codes (NCs). In the NC “Requirements and Operational Procedures in Emergency” – which is expected in 2014 – this specific topic will be regulated in detail.

In Austria, the ELWOG regulates the responsibilities for the grid restoration after a blackout. In this act, the responsibility for the restoration of the transmission grid is addressed. Further details for the restoration of the distribution grids are not sufficiently elaborated. A regulatory duty for the DSOs, and therefore financial compensation for their local grid restoration plans to support the efforts of the TSO, cannot be found – neither in Austrian nor in European laws.

Strategies

After a blackout the related restoration process for re-energization is based on two main principles: In the **top-down strategy** – in case of stable voltage from neighbouring TSOs – the external voltage sources from tie lines are used to reenergize a separated severely disturbed system. In the **bottom-up strategy** a self reenergising within the grid area is required, followed by resynchronisation with adjacent areas.

Depending on the countries regulatory demands, one or more restoration concepts within the transmission grid and/or the distribution grid can be chosen. In several federal states in Austria these regional restoration concepts are clearly defined and regularly trained. Nevertheless, this approach - including the topic of the legal and financial regulation - has been interpreted controversially among several stakeholders.

COORDINATION AND BENEFITS

Coordinated Approach

There is a large number of different blackout scenarios including varying possibilities of grid component failures. Based on several simulations, merely the restoration of the Austrian transmission grid – assuming ideal condition with a full availability of all grid components – is estimated to take up to 10 hours. The economic costs of one hour blackout vary on a winter day in Austria – according to the calculations from APOSTEL (Austrian Power Outage Simulation Tool of Economic Losses) [2] – from 30.9 Mio. Euro (at 1 a.m.) up to 186.5 Mio. Euro (at 1 p.m.).

Unless independent action taken by a **DSO**, re-energization of the distribution system might take several hours with severe impacts on the population and economy. Otherwise, if a DSO has the technical and organisational ability to start a local grid restoration, it will be advantageous to act in parallel to the TSO. In order to avoid redundant multiplicity these restoration plans need to be pre-coordinated with the superior TSO and have to be trained, based on simulations and real tests, periodically.

The **TSO** on the other hand has to fulfil the legal requirements. As long as the local grid restoration does not negatively affect the TSO's achievements, these local islands should be able to develop separately.

Benefits

In case of a bottom-up grid restoration, the benefits of the start of regional islands can be listed as followed:

1. Increased flexibility by additional options for the starting areas, taking into account the variety of possible disturbance characteristics
2. Fast supply of auxiliary power of essential grid and power plant facilities increase their availability during the whole grid restoration
3. Quick restoration of urban centres and therefore reduction of the social impairment due to the loss of infrastructure
4. Reduction of the economic losses due to a shorter outage time
5. Synchronisation of the DSOs' and the TSO's islands result in a better grid stability

These significant advantages justify the efforts for a coordinated approach of all stakeholders – TSO, DSOs and power plant operators. Taking the following key factors into consideration, this common approach will gain the fastest and most stable solution for the reenergizing of all consumers.

TECHNICAL KEY ASPECTS

Operation Centre Requirements

One of the most crucial factors is the availability of an independent and reliable communication structure, which is necessary to establish an access to all crucial partners during the grid restoration. These partners are the TSO, the DSO, the power plant operators as well as the emergency task forces. The communication between the TSO's und DSO's control centres shall be designed to guarantee a high level of security, either via a separated wired communication, through an independent radio network or via satellite telephones. Regardless the chosen system, a periodical testing is required to ensure its reliability.

Furthermore, for all grid operators it is of great importance to have a visual overview of the neighbouring or superior grid status. The Austrian Awareness System (AAS) and the Regional Alarm and Awareness System (RAAS) are tools with the aim of information interchange among grid operators.

Additionally, a dynamic frequency time course has to be displayed in the control centre with an adequate timely resolution of at least 100ms.

Power Plant Specifications

The power plant where the island restoration begins needs to be equipped with an emergency generator or a comparable installation, which is able to provide the plant's auxiliary power supply. For a stable islanded grid restoration it is essential that the starting machine configuration, consisting of one or more generators in parallel, is able to operate stable at no load, before the first load switching action. Furthermore, the ratio of the rotating energy at rated speed to the switched consumer load determines the gradient of the frequency. The drop in frequency must be compensated by the primary control machines. In this context the key parameters are a sufficient control speed and an adequate governor parameter set.

To avoid poorly damped oscillations due to governor interactions of the generators – caused by various mechanical time constants of the mechanical systems, nonlinearities or inadequate parameter settings – only selected and qualified units shall take part in frequency control. Generators only providing rotating energy at rated speed are advised to be operated at fixed active power output respectively valve position. Additionally, the application of this basic principle contributes to avoid problems during the variation of the frequency in the islanded grid, e.g. before the synchronization of two islands.

Dispersed Generation

Dispersed generation units have protection systems monitoring several parameters like frequency or voltage level. If one of these parameters is not within certain limits the generation unit is automatically disconnected from the grid, e.g. in case of a local disturbance or a blackout. When voltage and frequency return to predefined limits, the dispersed generation units are reconnected autonomously to the grid. Once these generators are reconnected they start to feed electrical power into the system, which might cause major problems during an islanded grid restoration.

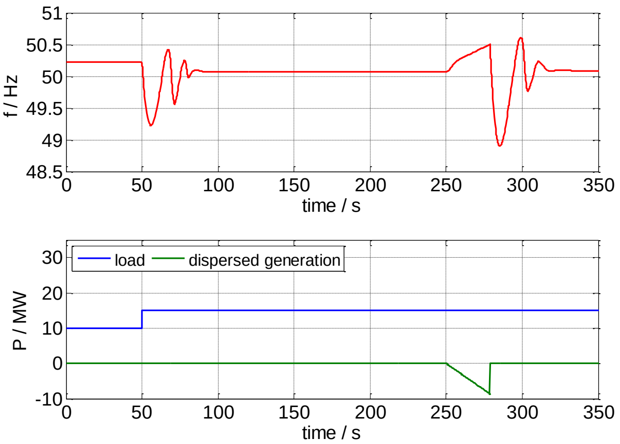

Figure 1: Impact of dispersed generation during grid restoration (simulation)

Based on the behaviour of the hydro governors, the steady-state frequency after a load connection will be lower than before, e.g. connection of a MV feeder as shown in Figure 1. Generators situated on this feeder are automatically reconnected to the grid – which can be seen at the time stamp of 250 seconds – and start to feed electrical power into the grid. As a result of the increase of dispersed generated power the frequency will be affected depending on the rate between installed dispersed generation to central power generation. If the frequency increases over 50.2 Hz dispersed generation units should decrease their power, but especially older ones will not fulfil this requirement. The dispersed generation units are disconnected by its protection devices if the frequency exceeds a fixed limit. In this simulation 50.5 Hz was chosen. The loss of the additional generation has the same effect as a load connection – the frequency decreases instantaneously.

To avoid this disrupting behaviour in the critical start of an islanded grid restoration one measure is to begin with a higher start-frequency. Therefore, the previous island grid restoration test in the KELAG Netz was successfully accomplished with a starting frequency of 51.5 Hz.

Cold Load Pick-Up

Another relevant topic during grid restoration is the load characteristic after re-energization, in literature described as “cold load pick-up”.

Reconnecting a shedded load group usually leads to an increased power demand at power-on time than it was previous to black out. The effect of the outage duration on the raise of the post-outage power to the pre-outage power was studied. The investigations led to the result that the repowering of shedded loads is followed in the first time after the outage by a high, short peak in power demand due the inrush and starting-current of electrical devices such as asynchronous machines and discharge lamps (Figure 2).

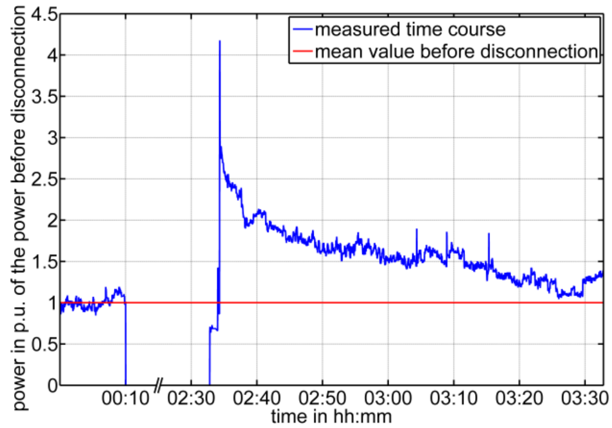

Figure 2: Example for a “cold load pick-up” in LV

That peak lasts a few seconds and is followed by slowly decaying power demand due to thermostat controlled processes. Concerning a high amount of thermal controlled devices in the grid-part to be picked-up, the outage time plays an important role. Long outage durations lead to a simultaneous start of all those thermal controlled devices causing a high power demand. This demand decreases again over time due to diversification caused by the different character (time constants) of the devices.

The unavoidable raise of load on pick-up can have a significant impact on the frequency stability in the early grid restoration stage but by the knowledge of the load-group’s pick-up behaviour it can be considered in principle.

Synchronisation

Regarding the issue of island synchronization one focus of the recent tests at the KELAG Netz in 2011 was put on the synchrocheck equipment and its parameterization by using the functionality of distance protection relays. Several synchronization attempts of the islanded grid to the interconnected ENTSO-E system have been carried out and measured for offline evaluation.

As a major result it was shown that the synchronization of the islanded distribution system to the transmission system was accomplished successfully for all attempts. The measured differential angles where analysed regarding possible optimization of the synchronizing devices. Transient oscillations due to the tolerated angular difference were recorded with Phasor Measurement Units to assess the stress of the link between islanded and superior grid.

3-STEP APPROACH

To establish an integrated and successful grid restoration plan within all participating companies, a predefined process has to be established. Within the KELAG Netz, an approach in three steps has been installed:

Step 1: Islanded Grid Restoration Tests

In a first step - and based on a coordinated restoration plan - the behaviour and the interaction between the grid and power plant components have to be tested and verified. To achieve realistic results, this can only be done by grid restoration tests. The aim of these tests is to train the operators and to collect measurements for a simulator. The gained knowledge and experience will be essential for the following steps.

The training sequence during these tests includes the establishment of a tele-conference, the black-start of generators and the synchronization of the islanded grid to ENTSO-E. Loads are simulated by using pump-loads. Additionally, the fall-back into islanded operation with imbalanced initial situation is tested.

Step 2: Software Simulations

The supreme premise of islanded grid restoration tests is to avoid any influence on customer installations. The resulting gap from the tests to a potential real grid restoration after a major blackout is covered by simulation models with varying levels of detail, as shown in [3, 4]. Therefore, simulation tools in the context of grid restoration are essential to be able to simulate the islanded system behaviour in case of a real emergency case. Especially the first critical steps of grid restoration require simulation models with a very high level of detail. Major characteristics of these models are the detailed representation of all significant components such as generator, hydro turbine and especially the speed governor behaviour including nonlinearities and needle-deflector control schemes. To determine the quality of the model and optimize the model settings an evaluation based on real measurements is indispensable.

Step 3: Operator Training

In the final step a simulator-based training is performed in order to test the real-time interaction between all grid and power plant operators. The software should be able to simulate multiple joined electrical networks with its operation centres. Further, it should simulate the power plant, grid and protection behaviour in real-time and integrate the technical key factors mentioned above. To verify the existing grid restoration plans, the trainings should be based on these predefined scenarios.

The focus during this training lays mainly on the interaction between the different operation centres, including the communication, the coordination regarding frequency control, the implementation of the Awareness System and the process regarding synchronisation of islands. An important issue is the topic of terminology between the different grid operators and between grid and power plant operators, which has to be defined in advance.

CONCLUSION

Recent developments in the European energy sector have increased the probability of a blackout. To meet this challenge, restoration plans have to be revised and coordinated. Therefore, organizational as well as technical issues need to be considered.

Autarkic grid restoration of capable DSOs – in coordination and parallel to the superior TSO – in case of major blackout scenarios can accelerate the overall grid restoration procedure significantly and contribute to an effective reconnection of consumers, especially of critical infrastructure. Furthermore, the flexibility of the overall restoration concept is enhanced taking into account the manifold variation of blackout scenarios.

Several technical aspects need to be reviewed in detail, considering increasing amount of dispersed generation and the topic cold load pick-up, which are currently not considered thoroughly. A regular training of the TSO, the DSOs and the power plant operator should be mandatory for all parties involved.

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