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POWER SYSTEM RESTORATION OF EASTERN GRID OF BHUTAN USING DIGSILENT POWERFACTORY

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Abstract—**Power system repair and restoration is a novel problem in power system as it is concerned with the reliability. However, it is a challenge to achieve a highly reliable power system due to various contingencies occurring in it. These unpredictable events result in overloading of some part of the system and sometimes it even followed by cascade tripping of transmission line, power plant and result in a total shut down of the system. Therefore, it’s very important to have black start plans for the system and prepare a black start operation procedure to recover the system in minimum duration. This report presents some to strategies to restore the eastern grind of Bhutan in the event of total and partial black out.**

Keywords—**Restoration, blackout.**

I. INTRODUCTION

Power security and dependability are regarded extremely crucial in today's environment. However, no system can be guaranteed to be 100 percent reliable. System disruptions can occur in an integrated power system owing to a variety of factors such as system faults, lightning strikes, extreme weather conditions and so on. Such disruptions in a system might cause a component of the system to collapse or even cause the entire system to shut down, resulting in a system blackout, hence the capacity to recover from such catastrophic occurrences is essential. It is thus vital to have a well-planned restoration strategy under various scenarios of partial and/or total blackout of the system to restore the system in the shortest possible time.

In the case of a blackout, the first few minutes are crucial, and it is critical to make the proper decision straight away to restore the system quickly. Any gap or delay in making the correct initial selection might be quite expensive. As a result, it is critical that all operational employees and authorities involved in grid operation have a complete understanding of the restoration method to reduce the time it takes to restore the system after a blackout.

During the restoration process, system operators, power station staff, and substation personnel must all work together to restore grid normalcy. Black Start is one of the major activities involved during the restoration of the grid by bringing on bar the self-starting generators, which are generally hydro and gas-based stations with local stand-alone supply sources [1]. Black start in power system basically means restoring a generating unit with its auxiliaries supplied by diesel generator set or battery and extending power supply to loads after dead bus charging and energizing a transmission line to seek loads [2].

Based on the system restoration tactics used, a 'top down' strategy might be used, in which the afflicted area is restored with the help of the neighboring power grid. However, in the event of a wide-spread blackout or an isolated grid, there may not be a neighboring grid to supply, necessitating a 'bottom-up' strategy. In this situation, the restoration must start with pre-selected generating units that can start on their own. The self-starting generating units are normally black started with local diesel generator sets, and subsystems are progressively formed around the self-starting units with some radial load, gradually enlarged by synchronizing those tiny sub-systems among themselves, and subsequently with the main grid.

Hydro power plants require relatively little initial power to start and thus are frequently categorized as black-start sources. This paper works on presenting on the development of a restoration plan of the eastern grid of Bhutan in the event of total blackout.

II. BLACKOUTS

Extended blackouts of the electric grid can and have been caused by equipment failures, operator errors, natural disasters, and cyber-attacks as further exampled in this chapter. Even if such catastrophes are uncommon, being prepared is thus essential, since prolonged power disruptions put their human lives, national security, energy economy in jeopardy. Because most of the generating units cannot resume without being connected to a live grid, the system operator is reliant on a few units that can start. It is expensive to allocate and maintain these units. This can have a significant impact on the restoration's security and timeliness. Restoration plans are an absolute necessity in power system operation.[3]

Cascading failure is a process in which the failure of one or a few elements in a system of linked parts can cause the failure of other sections, and so on, as seen in power transmission, computer networking, banking, transportation systems, creatures, the human body, and ecosystems. A single breakdown in an electric power system can result in a complete system blackout. These are complex sequences of dependent outages that occur with a low probability yet are not uncommon. As a source of significant economic loss, this is a problem that needs to be remedied, or at the very least appropriately addressed, as flaws are unavoidable. To better understand blackouts, some examples are provided below.

A. 2012 Indian blackout:

On July 30 and 31, 2012, there was a major blackout in India that affected over 600 million people. On July 30, nearly the entire north region covering eight states was affected, with a loss of 38000 MW of load. On July 31, 48 000 MW of load was shed, affecting 21 states. These major failures in the synchronously operating North- East- Northeast- West grid were initiated by overloading of an interregional tie line on both days [8–10]. This blackout is infamously dubbed as the biggest outage in the history of outages around the world: Outages are usually ranked on person-hour of the disruption. The 1020 MW Tala hydropower plant of Bhutan played a vital role in energizing the major transmission lines during the restoration process: yet another reminder of the glorious Indo-Bhutan friendship.

Fig. 1: Satellite images depicting the extent of the 2012 Indian blackout.

B. 2003 Italy blackout

On September 28, 2003, there was a major power outage that lasted 12 hours in Italy and 3 hours in portions of Switzerland. It was the largest in a series of blackouts that hit the country in 2003, affecting 56 million people [6]. The tripping of a main tie line from Switzerland to Italy due to tree flashover was the catalyst. Then, due to tree contact, a second 380 kV line tripped on the same boundary. The consequent power shortage in Italy led Italy to lose synchronization with the rest of Europe, and distant relays tripped lines on the France-Italy interface. The 220kV link between Italy and Austria suffered the same fate. As a result, the final 380 kV line between Italy and Slovenia was overloaded and tripped. The frequency of the Italian system began to decline due to a considerable quantity of power scarcity. The frequency decay was not properly managed, causing the generator to trip owing to under frequency. As a result, the whole Italian system failed in a matter of minutes, resulting in a statewide blackout [7].

C. 2003 U.S.- Canadian blackout

A widespread power outage occurred throughout parts of the northeastern and midwestern United States and the Canadian province of Ontario on August 14, 2003, affecting an estimated 10 million people in Ontario and 45 million people in eight U.S. states [5]. The initiating events were the out- of- service of a generating plant and the following tripping of several transmission lines due to tree flashover. Key factors include inoperative state estimator due to incorrect telemetry data and the failure of the alarm system at one of the control rooms.

Fig. 2: Satellite image of 2003 US-Canadian blackout

D. 2016 South African blackout:

On September 28, 2016, there was a significant power outage in the South African electricity grid, affecting around 850,000 consumers [13]. Before the outage, the overall demand on the power system, including losses, was 1826 MW, with roughly 883 MW supplied by wind production, indicating a high renewable penetration [14]. A violent storm occurred, damaging numerous distant transmission towers. Within minutes, the grid had lost roughly 52 percent of its wind power. This shortfall had to be made up by importing electricity from a neighboring statevia atie link. The connections could not handle the drastically increased power flow.

E. 1996 Western North America blackouts

On July 2, 1996, a disruption occurred, resulting in the Western Electricity Coordinating Council system dividing into five islands and affecting over two million consumers. Except for some customers who were without power for up to 6 hours, most consumers had their power restored within 30 minutes [4]. A single phase to ground failure on a 345 kV transmission line caused by a flashover (arc) when the cable sagged near to a tree. A similar blackout happened the next day, July 3, which was similarly caused by a tree flashover on the same line.

F. 2015 Ukrainian blackout:

On December 23, 2015, a Ukrainian distribution company, reported service outages to customers [11]. The outages were due to a third party's illegal entry into the company's computer and supervisory control and data acquisition (SCADA) systems: seven 110 kV and twenty-three 35 kV substations were disconnected for 3 hours. According to later assertions, the cyber attack disrupted further parts of the distribution grid, forcing operators to resort to manual mode. The Ukrainian news media reported on the incident, conducting interviews, and concluding that a foreign adversary remotely manipulated the SCADA distribution management system. According to the distribution company, the disruptions were estimated to have affected over 80,000 people. However, it was eventually discovered that three distinct distribution firms had been targeted, leading in several disruptions that affected around 225,000 people in various places.

III. POWER SYSTEM RESTORATION

Modern power systems are designed to have a high level of reliability [15], which is why power system operation should be closely monitored so that it operates within its safe operating limits. Despite the high level of reliability, outages in the power system still prevail. Often, an outage is only in a portion of the power system, and it can be restored using the power from the healthy section. However, in case of an outage affecting a large area: a blackout, there may not be neighbor to help the system. In this case, system restoration must begin from pre-selected generating units with the ability to start themselves [15], called a black start generator. The process of restoring a power plant to operational status without the need of external energy sources is known as black start. The most common black start generators are hydroelectric generators, diesel generators and gas turbine generator.

Hydroelectric generators require small amount of starting power, and they respond quickly to power other plants which do not have black start capability. In a primarily hydro system such as in the Bhutanese Power sector, focus is mainly given to response of the prime mover to sudden load pickups. Off-line dynamic programs and simulations are done to develop restoration plans depending on the prevailing generation, transmission, and load data. Large hydroelectric generators are usually linked to on-site diesel generator sets or a battery bank, which are started and used to power auxiliary buses as well as start the generator. Small diesel generators can supply enough power to start bigger generators of several MW capacity, which in turn can start other generators in the same power plant and then power other generators[16].

Black start capability is critical for power system restoration to have a quick installation of a new black start generator. During black start restoration, voltage and frequency management must be ensure. Both should be kept within their nominal ranges to ensure that no equipment breakdown would seriously impede the restoration process. As voltage stress is major hinder for a black start during the power system restoration. The black start unit should be able to absorb the produced reactive power from charging current produced by incoming generators, transformers, and transmission line. Self-excitation could be caused by a higher charging current indicating that it will result in an uncontrolled voltage rise.A black start procedure must be tested both in steady state and transient operating condition for feasibility test to operating voltage and power flow.[17]

A. The need for restoration

Restoration studies are useful for illustrating the rationale behind certain activities, such as the cause-and-effect reasoning behind the choice and sequence of operator operations, as well as the effects of those actions on the power system.[18]

Blackouts in the power system are uncommon. It is, nonetheless, critical to have strategies and mechanisms in place to deal with any situation, no matter how remote. After any power outage, it's critical to restore power as soon and as reliably as possible. A successful system restoration strategy minimizes the impact of an outage on consumers and the local economy while also lowering the risk of equipment damage. [19]

B. Constraints during restoration

The management of voltage and frequency, which must both be managed within a narrow band around nominal levels to ensure no equipment breakdown would substantially impede the restoration process, is one of the most important considerations in a restoration process. A restoration plan analysis must be carried out to ensure that it is feasible in both steady-state and transient operation situations. Restoration steady-state assessments include [20] load-generation balance, voltage control, steady state overvoltage analysis and reactive power absorption capability of black start units during charging of transmission lines. Other assessments such large induction motor starting, and their sequencing must be considered as well.

During black start, while energizing the lines charges currents could be very large causing black start unit to absorb large reactive power leading to self-excitation of the black start generator. Self-excitation will in turn lead to uncontrolled rise in voltage or equipment failure. Therefore, reactive power capability of black start unit should be properly studied whin it is being operated at leading power factor. Reactive power capacity of the black start unit when operated at a leading power factor. The installation of shunt reactors, synchronization of generating units as a block and minimizing the time between paralleling units online will help to reduce the probability of exposing a generating unit to the condition of self- excitation. It is also important to validate a restoration plan by simulation both for steady state and dynamic operating conditions.

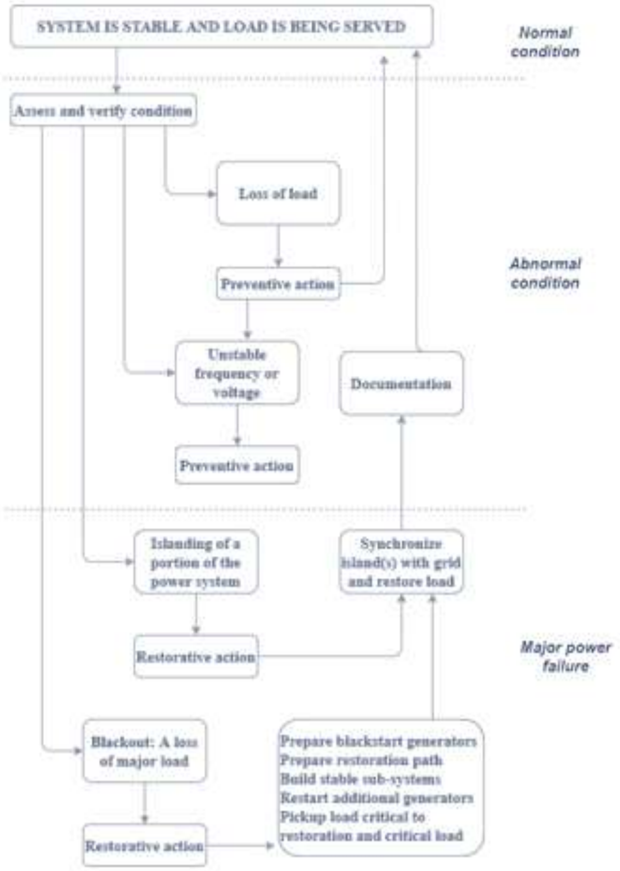

Fig.3: Power system failures and restoration actions

C. Power system restoration procedure

Power system restoration is a complex problem involving many generation, transmission and distribution, and load constraints [21]. A common approach to simplify this task is to divide the restoration process into stages such as preparation, system restoration, and load restoration [22].

In a typical restoration procedure: The system state is analyzed, initial cranking sources are recognized, and critical loads are determined in the first step. Restoration pathways are discovered, and subsystems are ignited in the next stage. These subsystems are then linked together to make the system more reliable. The majority of undelivered load are restored in the final step. [21-23]

D. Restoration Strategies

According to the restoration stages, restoration strategies can be categorized into six types [22], that is, build- upward, build- downward, build- inward, build- outward, build- together, and serve- critical. [23]

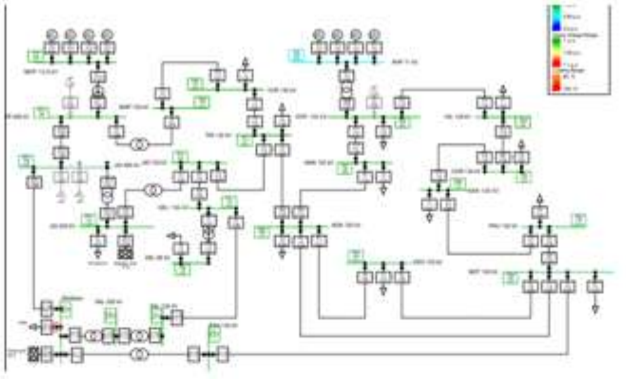

Fig. 5: Model developed in DigSilent PowerFactory

1) Build upward restoration

Many grids characterize as an island with black start capabilities that must be resynchronized as the restoration operation progresses. The key tasks involved in this restoration technique are black start unit starting, island restoration, and island synchronization.

2) Build downward restoration

Some smaller or more closely knit utilities with a lower voltage network to pool their black start power and provide it to nonblack start units, network energization, and nonblack start unit startup.

3) Build inward restoration:

Involves starting of a central generation station followed by basic network system.

4) Build outward restoration:

A ring transmission line is reenergized, and the restoration proceeds from this ring outward.

5) Build together:

Loads nearer to the generating units is picked up first.

Another way of classifying is discussed below:

1) Top down

In case of top-down restoration, the high voltage system is energized by using the black start units. In this method firstly the high voltage grids were established, followed using the sub-transmission network to reach selected plant. However, energizing lines in the bulk transmission system first is more difficult and will usually require larger generating units to be on-line but if successful, it will generally lead to a faster restoration of critical systems and loads

2) Bottom up

In case of bottom –up restoration the sub transmission is energized by using the black start units and it energize part to supply cranking power to larger units. Here, several simultaneous, independent “islands” are formed which are eventually been synchronized and the extra high-voltage grids are established when the lager plants are on-line. Although this method can make used of smaller black start units to restore large grids however, this method consumed longer duration to restore the system compared to top-down restoration method.

IV. METHODOLOGY

High quality modelling of hydro power plants for restoration studies with the continuous deregulation process, it is becoming increasingly vital to verify existing strategies for network restoration following blackouts in European electrical energy systems. High-quality computer models of the electrical system are required for this verification, as well as the ability to generate exact findings for all potential restoration scenarios. The power plants, which must be built with extreme precision, are the most significant components of these models [25].

Eastern grid of Bhutan consists of two hydropower plants namely Kurichhu Hydropower Plant (KHP) and Mangdechhu Hydropower Plant (MHP). Both the power plants have four number of generators of capacity 180 MW and 15 MW for MHP and KHP respectively. Therefore, total designed capacity is 720 MW and 60 MW respectively, with 10 % overloading capability which is true during the monsoon season. The power plant serves eastern districts of Bhutan, and the excessive power is being sold to India.

The model of the power system was developed as shown in Fig.5. A rudimentary validation process was used, i.e., checking the power flow to India in normal operation. The simulated value resembled closely with the data obtained from Bhutan Power System Operator. Moreover, the model was verified by various power system analysts.

Two restoration plans were developed and are discussed. The first plan connects MHP to the Indian grid and gradually restores the system. The second plan connects both the power plants and then proceeds with the restoration.

V. RESULTS

An outage was created by disconnecting Indian grid. This also checks for isolated grid operation of Bhutan grid. The grid frequency was seen to over-shoot and the system collapsed.

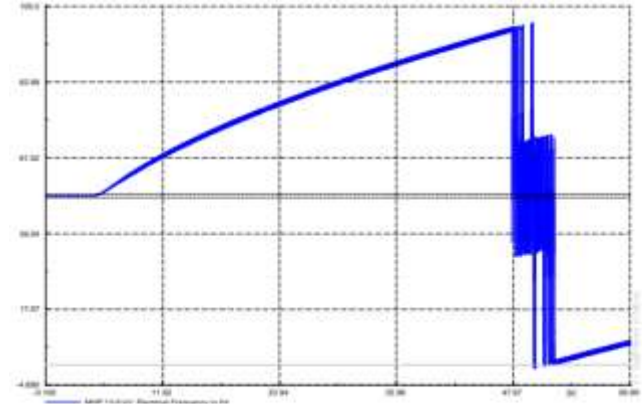

Fig. 6: Frequency overshoot upon disconnection of Indian grid

In both the restoration process, voltage profile of all the buses was monitored to not violate its limits as shown for one bus.

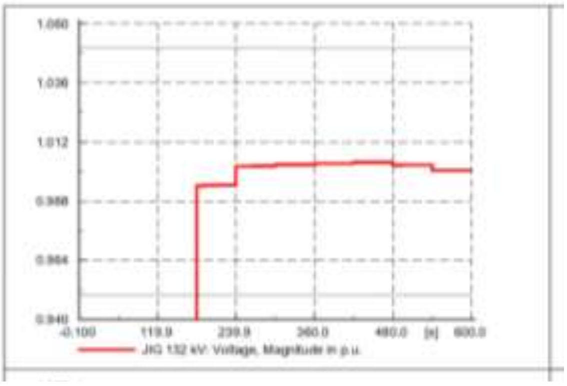

Fig. 7: Voltage profile of one bus during the restoration process

Both the discussed plans showed bus voltage profiles within their limits.

VI. CONCLUSION

Since the grid collapsed upon disconnection of Indian load, thus it can be concluded that the islanded operation of the cannot be possible. Differences between the two plans should be discussed to better weigh them as well. The former plan is restoring the system slower than the latter plan. However, India sells energy to Bhutan at a much higher rate than at what it is sold by Bhutan. Thus, this could make the former plan superior. On the contrary, a faster restoration process could decrease irregularities in industrial processes and normalize situations faster, resulting in a general superiority in productivity.

In case of a cascaded blackout through a neighboring grid, it is not reliable for a restoration plan to rely completely on the neighboring grid for restoration. Thus, islanded operation must be studied when it comes to restoration. This research further prompts discussions on islanded operation of the whole grid of Bhutan.

VII. REFERENCES

[1] P. Mukhopadhyay, V. Pandey, A. P. Das, C. Kumar, P. A. R. Bende, and K. K. Parbhakar, “Black Start Experiences for 400 kV Hydro Power Plant In Western Regional Grid of India,” 2016.

[2] P. Pentayya, A. Gartia, A. P. Das, C. Kumar, K. B. Out, and B. Start, “Black Start Exercises Experience in Western Region, India,” 2013.

[3] G. Patsakis, D. Rajan, I. Aravena, J. Rios, and S. Oren. Optimal black start allocation for power system restoration.

[4] North American Electric Reliability Council (2002). 1996 system disturbances

[5] U.S.- Canada Power System Outage Task Force (2004). Final report on the August 14th blackout in the

United States and Canada. Department of Energy and National Resources Canada.

[6] UCTE Investigation Committee (2003). Interim report of the investigation committee on the 28 September 2003 blackout in Italy. UCTE Report, October, 27.

[7] Andersson, G., Donalek, P., Farmer, R. et al. (2005). Causes of the 2003 major grid blackouts in North America and Europe, and recommended means to improve system dynamic performance. 1922–1928.

[8] Romero, J.J. (2012). Blackouts illuminate India's power problems. IEEE Spectr. 49 (10): 11–12.

[9] Gailwad, A. (2013). Indian blackouts – July 30 & 31 2012 recommendations and further actions, in IEEE PES General Meeting.

[10] Rampurkar, V., Pentayya, P., Mangalvedekar, H.A., and Kazi, F. (2016). Cascading failure analysis for Indian power grid. IEEE Trans. Smart Grid 7 (4): 1951–1960.

[11] Lee, R.M., Assante, M.J., and Conway, T. (2016). Analysis of the cyber attack on the Ukrainian power grid. SANS Industrial Control Systems.

[12] North American Electric Reliability Corporation (2017). 1,200 MW fault induced solar photovoltaic resource interruption disturbance report.

[13] Australian Energy Market Operator (AEMO) (2017). Black System South Australia 28 September 2016

[14] Yan R., Al Masood N., Saha T.K. et al. (2018). The anatomy of the 2016 South Australia blackout: A catastrophic event in a high renewable network. IEEE Transactions on Power Systems.

[15] J. W. Feltes and C. Grande-Moran, "Black start studies for system restoration," 2008.

[16] Feltes, J.J.W. and Grande- Moran, C. (2008). Black start studies for system restoration.

[17] K. Sun, Y. Hou, W. Sun, and J. Qi,. Black-Start Capability Assessment and Optimization.

[18] J. W. Feltes and C. Grande-Moran, "Black start studies for system restoration," IEEE Power Energy Soc. 2008 Gen. Meet. Convers. Deliv. Electr. Energy 21st Century, PES, pp. 1–8, 2008, doi: 10.1109/PES.2008.4596565.

[19] P. Pradhan, T. Deki, P. Wangmo, D. Dorji, D. Phuntsho, and C. Dorji, "Simulation and optimization of blackstart restoration plan in Bhutan using DIgSILENT," 2015.

[20] K. Sun, Y. Hou, W. Sun, and J. Qi, "Constraints of System Restoration," Power Syst. Control Under Cascading Fail., pp. 225–254, 2018, doi: 10.1002/9781119282075.ch6.

[21] Adibi, M.M., Borkoski, J.N., and Kafaka, R.J. (Nov. 1987). Power system restoration – the second task force report. IEEE Trans. Power Syst. 2 (4): 927–932.

[22] Fink, L.H., Liou, K.L., and Liu, C.C. (May 1995). From generic restoration actions to specific restoration strategies. IEEE Trans. Power Syst. 10 (2): 745–751.

[23] D. Lindenmeyer, H. W. Dommel, and M. M. Adibi, "Power system restoration - a bibliographical survey,"2001.

[24] K. Sun, Y. Hou, W. Sun, and J. Qi, "Restoration Methodology and Implementation Algorithms," 2018.

[25] C. Fa, "Importance of Modeling & Understanding," 2019.

[26] H. W. Weber, M. Hladky, T. Haase, S. Spreng, and C. N. Moser, High quality modelling of hydro power plants for restoration studies, vol. 35, no. 1. IFAC, 2002.

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