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Renewable energy impact into the restoration of electrical networks after a blackout

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Abstract : Electrical systems are the most complex systems and have great importance in modern life. They have direct impacts on modernization, economic, political and social aspects. The restoration of such systems following a major incident which could lead to blackout, requires a particular study of the phenomena which destabilize the network, and a particular analysis of the weak points and the strengths of the electrical system. The restoration is considered to be a very complex combinatorial problem due to the various constraints and criteria which must be taken into account, namely the start-up or restart of production units, energizing lines and transformers, restoring loads. The modern society depends on electricity, so fast food wanted after power system failures. The objective of this paper is to explore how renewable energy can shorten restoration time. The reason for the long restoration time is that the lack of flexibility in controlling current electrical equipment. The advantage of renewable energies or distributed production is that the production is close to the loads and does not depend on long transmission lines, For the simulation, the IEEE 39 bus and the North Algerian Transport Networks (NATN) will be used, in order to analyze the impact of renewable energies. The discussion will focus on different scenarios to study. The expected results are mainly summarized in the improvement of the start-up time of production units, acceleration of charge recovery, in particular critical loads and the stability of electrical networks.
Keywords : Electrical Networks, Blackout, Power System Restoration (PSR), Collapse, Restoration Strategies, Restart of Production Units (Black start Unit BSU), Cranking No Black Start Unit (NBSU), Renewable Source (RS).

1. Introduction

The study of the problem of restoring an electrical network following a major incident, which can lead to blackout, requires a specific analysis of the mechanisms, which destabilize the network. It is necessary to look at the network topology and analyze its weaknesses and strengths, and simulate situations that are so different from each other. Of course, the modeling of the components of the power system is important, but also the modeling of the fault causing the incident. Then it is necessary, to deepen on the process and the most effective actions to restore the network following a major incident and the blackout. The problem of restoration concerns all aspects of chronology and priority in the restoration of loads, the starting or restarting of production units, the recharging of lines and transformers. It is a combinatorial problem, deemed difficult by the multitude of constraints and criteria, which must be taken into account. Since electricity can not be stored in large quantities, it is produced and transported on a just-in-time basis. Produced in a production unit, it is then transported over long distances in very high voltage, and then transformed into medium voltage to enter cities by radials in order to be delivered to the customer. Finally, it is retransformed into base voltage in order to use on the big scale.

Several phenomena can affect part of the network or all of it.

- Loss of a radial network, due to starting or breaking of the overhead circuit breaker and affecting only part of the network.
- Simultaneous loss of several electricity transmission structures, resulting in the transfer of the energy transported to another, resulting in oversizing of the chain structures).
- Voltage collapse, due to the loss of several production units simultaneously.

- Synchronization failure, due to frequency differences between several points on the network and resulting in frequency reductions on the overall network.
- A short circuit caused by ignition with its environment.
- Operator’s errors.

The problem of restoring an electrical network following a blackout requires a specific study of the phenomena that destabilize the system. Knowing that the power system restoration (PSR) is considering a very complex combinatorial problem because of the various constraints and criteria, which must be taken into account, namely, restarting production units, energizing lines and transformers.

Several blackouts have occurred recently, such as the major disturbance in Western Europe in September 2003, in northern India in July 2012, in Pakistan in January 2015, the widespread power blackout in March 2015 in Turkey and in Algeria in February 3rd 2003, it is a technical incident at the El-Hamma power station, at 19:05 precisely, a failure of the gas station of the power plant is reported. It immediately triggers groups with a capacity of 400 megawatts (MW), this incident shutdown of all power plants in the country in thirty wilayas.

Such blackouts caused economic losses due to business disruptions, loss of production, as well as causing high safety risk to the public. In order to minimize losses, the system needs to be restored as fast as possible. However, this requires careful planning during the process of energizing individual power system components, such as generator units, transmission lines, substation buses, loads, and other facilities, back to normal.

2. Major Blackout Causes around the world

Major power outages that affected people around the world from 2011 to 2018 have been comprehensively reviewed. The highest duration of the blackout occurred in Bangladesh on 1 November 2014, it has of 24 h. The Indian blackout on 30 July 2012 has affected the highest number of people during history (620 million). The majority of causes of the blackout are related to transmission system operation, control and protection.

Table 1 shows 66 surveyed major power systems blackouts in some parts of the world from 2011to 2019.

Table 1. Analysis on blackouts around the globe and their percentage from 2011 to 2019.

Blackout Cause	Number Recorded	% of the Recorded Number
Weather/Trees	33	50
Faulty equipment or human error	21	31.8
Vehicle/Accidents	7	10.6
Animals	1	1.5
Over demand	4	6.1
Total	66	100

3. Impacts of Blackouts

Unplanned power outages and blackouts have significant impacts on businesses operating in the affected areas. Human activities globally are highly dependent on power supply to an extent that, when a power system collapses, many effects are experienced. In Figure 1, it can be seen that power blackouts have social, economic and political impacts on today’s human activities.

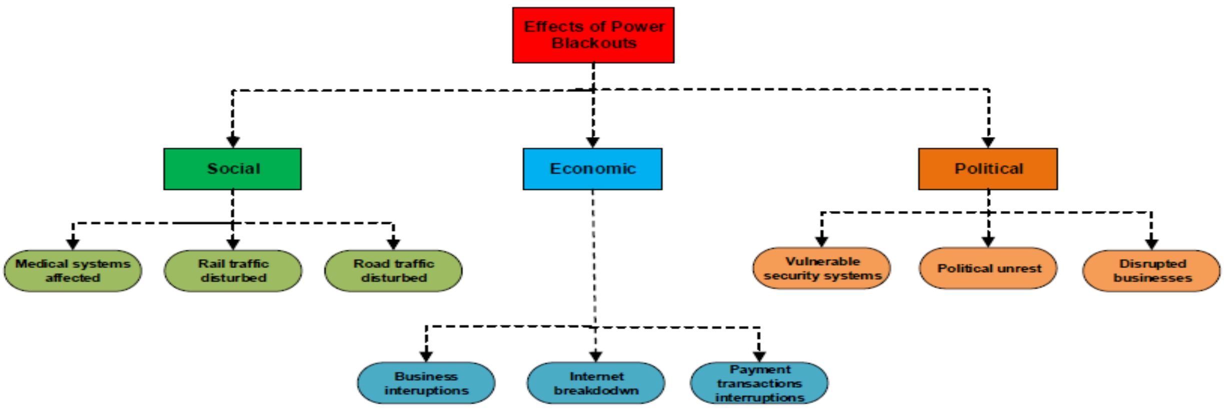

Figure 1. Major electric power system blackout causes.

4. Restoration Techniques of electric network (Power system Restoration)

There are two main restoration techniques to restore a blackout system, The first technique is called '**build-up'** technique, where the system is sectionalized into subsystems or islands. The islands formed should fulfill the power generation-load balance and voltage limit constraints. This can be done by ensuring that the total capacity of generators in the island is able to fulfill the maximum load demand of the island. The availability of black start (BS) generators in each island must also be considered. The BS generator, which operates using auxiliary supply, is required to initiate the reenergizing process. Parallel restoration of the islands has carried out before resynchronizing the islands to a complete system. The main premise of this technique is to reduce the total restoration time and avoid system blackout from reoccurring due to recurrent disturbances in the affected island. In reenergizing power system units such as generators, buses, and loads in the islands, two approaches are available. The first is to energize the islands backbone, which contains the main units such as BS generator, non-black start generators (NBS), and critical loads (CLs). Once this step has been carried out, the islands are resynchronized, and the rest of the units will continue to be energized. The second approach is to energize all the power system units in the islands before the resynchronization process has carried out.
The second technique has called '**build-down**' technique, where the 'bulk network' has energized prior to resynchronizing loads and generators. This process has carried out without sectionalizing the system into islands. Loads and generators will be energized in parallel.
Since the main objective of the restoration process is to restore the system within a minimal time, the 'build up' technique is commonly preferred. For example, this technique has been applied to restore the power system network in the British network, Mexican network.
Many researchers have proposed power system restoration methods based on this technique. They using several methods in order to sectionalize the electrical network into islands, where each island will be restored independently before connecting all islands.

5. Impact of renewable energy in power system restoration

Modern society is dependent on electricity, so fast restoration has desired after power system blackouts. Restoration passes through four stages, taking an average of 12 h:

1- Post-disturbance evaluation (30–60 min);
2- Energizing of islanded transmission lines;
3- Reconnections of generators and load to the transmission line islands;
4- Resynchronization of transmission line islands which generators and loads have reconnected to them.

The objective of this paper is to explore how the renewable energies, can shorten the restoration time. The reason for the long restoration time is that present power equipment's lack of control flexibility. Voltage control is by slow generator field excitation. Other methods of voltage control are by operating transformer tap changers, connecting/disconnecting shunt capacitors/inductors.
The MVA rating of generators is often too small to supply auxiliaries and loads to stabilize frequency. The benefit of renewable energy or distributed generation is that generation is near to loads and does not rely on long transmission lines. In Germany, Denmark, Japan and USA, renewable energy sources such as wind, solar and storage (batteries) are added to traditional energy sources (oil, gas and coal) to form micro-grids.
The research shows that:

(i) Blacked-out transmission lines can be reenergized speedily without overvoltage;
(ii) Renewable energy or distributed generation have active power to energize the auxiliary motors of pumps and fans of power plants during dead start.

The authors can show that voltage support from renewable energy or distributed generation facilitate the reconnection of generators and loads. The research follows the practice of breaking the transmission line system by circuit breakers into several transmission line sections and charging the voltage of each section. Paralleling the reconnection of generators and loads in each section shortens the restoration time. In the final stage, the island sections have resynchronized to complete restoration. Active power, available from renewable energy, facilitates frequency control in the resynchronization stage.

6. Power system restoration constraints

During the recovery of power system several constraints must be satisfied. The starting times of NBS generators and their start-up power requirements must satisfy certain constraints. During restoration, some NBS units are not ready to receive cranking power until after a certain time interval ($Tjmin$), while others need to start within a certain interval ($Tjmax$) or they will become unavailable for a considerable time delay. In addition, all NBS units have their start-up power requirements ($Pjstart$) that must be supplied by the system for the units to start. In general, power systems can have more than one BS generator. The selection of the BS unit to crank a NBS unit depend on the length of the optimum transmission path between them and the generation capability of the BS unit at the time of the NBS unit starting. On the other hand, the sequence of load pick up depends on the value of the load to be picked up and the available generation capability of connected generators at the time of picking up that load. Based on these definitions, the constraints can be formulated as follows:

6.1 Starting time constraints

Considering the appropriate time interval to start the NBS unit, the starting time must satisfy the following constraints.

$$Tjstart \geq Tjmin \qquad j = 1,2,\dots\dots\dots M, \text{ if } Tjmin \text{ exist}$$
$$Tjstart \leq Tjmax \qquad j = 1,2,\dots\dots\dots M, \text{ if } Tjmax \text{ exist}$$

To consider the time needed to energize the optimum path leading to the NBS unit j :

$$Tjpath - opt \leq Tjstart$$

Where $Tjstart$ is the starting time of NBS unit j and $Tjpath - opt$ is the time taken to energize the buses and branches consisting of the optimal path to NBS unit j.

6.2 Start-up power requirement constraints

$$Pigen - opt\ (t) \geq Pjstart\ (t) \qquad for\ i = 1,2, \dots \dots \dots, Z\ and\ j = 1,2, \dots \dots \dots., M$$

Here, $Pigen - opt$ is the generation capability function of cranking unit i selected according the optimal transmission path found by the optimization algorithm, $Pjstart$ is the start-up power function of NBS Unit j, and Z is the number of BS units in the power system.

6.3 Load pick up constraint

$$\sum_{i=1}^{NL} Piload(t) \leq \sum_{J=1}^{NG} Pjgen(t) + Pwindfarm(t)$$

Here, $Piload$ is the load power of the i_{th} picked up load, $Pjgen$ is the power generated by the j_{th} connected generator, $Pwindfarm$ is the wind power, NL is the number of picked up load nodes, and NG is the number of connected generators.

6.4 The bus voltage constraint

$$V_i^{min} \leq V_i \leq V_i^{max} \qquad i = 1 \dots \dots \dots \dots. nbus$$

6.5 The branch power capacity constraint

$$S_{ij}\ (t) \leq S_{ij}^{max} \quad i = 1 \dots \dots \dots \dots nbus, j = 1 \dots \dots \dots.. nbus, i \neq j$$

7. Simulation and expected results

For the simulation, the IEEE 39 bus will be used, in order to analyze the impact of renewable energies. The discussion will about different scenarios to investigate such as:

- Replacing the generator by renewable energy source, wind power, photovoltaic power.
- Increase the power generation by injection a renewable energy source in the same bus.
- Injecting renewable energy sources into the load nodes.

The expected results will be

- Improvement of the start-up time of NBS production units.
- Acceleration of load recovery especially critical loads.
- Stabilization of the tension profile and to avoid collapse when energizing the lines.

In our objective also to apply the simulation on the North Algerian Transport Networks (NATN).

It remains to say that the operation of restoration of electrical networks after a general or partial outage is a very complex operation and the obstacles that we have encountered so far is summarized in two points, the simulation tool and the achievement topology of the North Algerian Transport Networks (NATN).

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