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Département de Recherche Opérationnelle
Faculté des Sciences Exactes, Université de Béjaïa
Laboratoire de Modélisation et d'Optimisation des Systèmes (*LAMOS*)

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Power system reliability modeling and decision making for quality of service emprovement under smart system integration and renewable resources insertion

Fairouz Iberraken*, Rabah Medjoudj**
Djamil Aissani***

*, **Electrical Engineering Department, University of Bejaia, Algeria, 06000
fairouziberraken@yahoo.fr , r.medjoudj66@gmail.com
***Operational Research Department, University of Bejaia, Algeria, 06000
lamos_bejaia@hotmail.com

***Abstract*— This paper deals with the contribution of smart systems and renewable resources on the continuity of service of a conventional power network. It is based on a model of generation, transmission, distribution, and consumption of electricity. The rare and dreaded events that occur on power systems and discussed in this work are blackouts. The models required to highlight the cascading degradation of the system leading to a blackout situation are based on a competing risk of failures occurring on transmission components and/or a shock arrival due to a loss of a generator. The degradation states probabilities are expressed using the loss of load probability model; and the arrivals of shocks are modelled using homogeneous Poisson process. However, the network restoration modelling is assumed by steady state graphs method. A first question posed in this issue is: How smart systems can mitigate the risk of these events? The decision making on their integration and on the insertion of renewable energy sources in the conventional networks is under uncertainty. A second question posed is: How smart grids can reduce the investment expenses on the insertion of these sources? The objective of this work is to try to respond objectively to those questions using mathematical models with a case study proving their applicability.**

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I. INTRODUCTION

A typical large blackout has an initial disturbance or trigger events followed by a sequence of cascading events [1]. The progression of blackout can be divided into several phases; the diagram shown in Figure 1 clearly describes these latest which are: precondition, initiating events, cascade events, final state and restoration. Among these five phases [2] [3], cascade events can be further divided into three phases in the process of some blackouts: steady state progression, triggering events and high-speed cascade. This major problem is a perfect opportunity for next-generation energy technologies integrity. Smart systems combine traditional grid, information and control technologies via adding sensors and intelligent devices. With smart meters, smart grid is able to collect real-time information about grid operations, through a reliable communications network deployed in parallel to the power transmission and distribution systems. They are based on models of their environments which may be implicit or explicit.

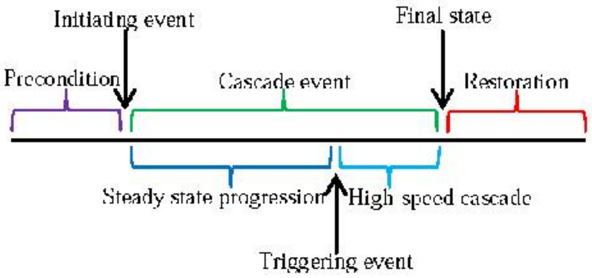

Figure 1. phases of blackout

The models determine for what sensors are used and where they are placed, how measured data is analysed to determine appropriate responses, and the types and locations of responders. In many cases, models of the environment are probabilistic and deal with rare events probabilities expressed by the loss of load probability (LOLP) or the loss of energy probability (LOEP). The treated issue consists on modeling the blackout by considering the degradation cascade following the failure of system components and addresses the loss of generators as an arrival of shocks following a homogeneous Poisson process.

When the amplitude reaches a certain threshold (a loss of a determined value of MW) the blackout occur. LOLP is a projected value of how much time, in the long run, the load on a power system is expected to be greater than the capacity of the generating sources. The generating system failures can occur into two ways: either through units' failures or through load increase. In recent publications [4] [5], the authors have generalized the use of LOLP as a reliability index of multi-states systems including transmission and distribution system. They have assimilated LOLP to a failure probability function and automatically the reliability. Considering S and D as the supply and the load demand respectively, they compute the reliability (R) of a multi-state system (MSS) as:

$R = Pr(S \geq D)$ or $R = 1 - LOLP$ (1)

Using the well-known formulation of the LOLP given in several publications and developed in the following section, they generalized the MSS reliability index R as: $R = \left(\frac{1}{\sum_{j=1}^{M} T_j}\right)\sum_{j=1}^{M} P_r\left(S \geq D_j\right)T_j$. Where the operation period T is divided into M intervals and each interval has T_j duration and a D_j required demand level. In the same context, using a series parallel system, Taboada *et al.* [6], calculate the availability of each part of the power including transmission and distribution system. In this paper, this modeling is used to formulate state probabilities of the degraded system as given in Fig 2.

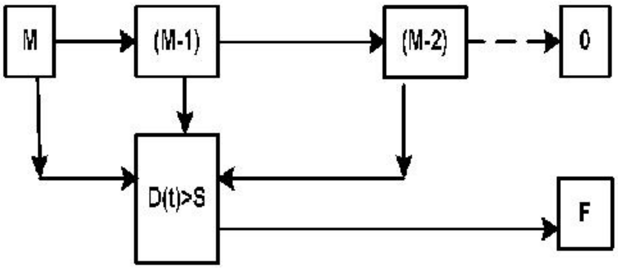

Figure 2. System states diagram subject to two failures processes where M, $(M-1)$, are degradation states, 0 is a degradation failure state and F is a catastrophic failure state.

Are designed by W_i, the threshold value of the degradation level when the system sojourns in state i, C_f the threshold value of the degradation failure, state 0 and S the critical threshold value for the shock process. The system goes to the catastrophic failure state F when $D(t)>S$. State M as the first state and the system is assumed to be as good as new. Practically, state 0 indicates a major failure in the system with a partially loss of the load. However, the catastrophic failure represents le blackout. The reliability of the system depends on state probabilities as given by equation 2.

$$R_M(t) = P[state \geq 1] = \sum_{i=1}^{M} P_i(t) \quad (2)$$

The network reconstruction after the blackout is modeled using Markov chain method as given in Fig 3. It is stated that based on three experiences of the Algerian, Italian and American blackouts occurred in 2003, a lot of efforts may be made to reduce restoration times. Regarding the delays of turbines starting, it is demonstrated that renewable sources can play an important role in this issue, thanks to the instantaneous delivery assured using batteries storage. The technical-economic compromise awareness among electricity networks managers the need for the use of tools to support the decision, which must be based on new quantitative and modeling approaches closer to the physical reality. A particular interest is given to the contribution of both integration of smart grids and insertion of renewable sources to better manage the peaks of demands, to reduce power losses and to increase the availability of electricity. The achievement of this goals depend on the engagement of managers and the comprehension of customers to adopt the decisions and how they are committed to follow the orientations going ahead the citizen gesture gathered in energy efficiency. This issue is supported using economic criteria inspired from game theory as developed recently by Medjoudj *et al.* [7]. Several countries have already taken a step ahead in the field of smart grids integration in the context of sustainable development. The founding and the orientations of this investigation could be beneficial to be applied to the Algerian case, knowing that this country have an interesting solar deposit estimated between 7 to 8 months of sunshine with a large area of its southern part.

II. DEGRADATION PROCESSES MODELING

Power transmission networks are heterogeneous systems with a large number of components that interact with each other through various ways. When the limits are exceeded for a component, it triggers its protective device. Therefore, it becomes faulty in the sense that it becomes unavailable to transmit electrical energy. The component can also fail in the direction of misoperation or damage due to aging, or low maintenance. In any case, the power will be redistributed to other network components, according to the laws of the mesh nodes and electrical circuits, or by manual or automatic redistribution. This power will be added to the already existing power carried by these components. Therefore, their overload is inevitable if they are at their operating limits. So, this scenario leads to the propagation of failures through the network. This propagation can be local or it may be general, if the overload caused by the first degradation is very important. Any future deterioration comes to instantly change the configuration and operational parameters of the network. It makes the system unstable and the seat of transients very violating the majority of cases, such as the collapse of voltage and frequency and the loss of synchronism. Usually, the system can be pulled back to normal condition by its protection and control system. But, sometimes, the system cannot return to normal condition in good time and some new events can trigger the cascade incidents, which may interact and rapidly worsen the situation. Finally, blackout can happen. Then, every disturbance triggers a next one, and so on; the system will pass from state i to state $i-1$ due to gradual degradations or to state F due to random shock as given in figure 2.

Let us consider a repairable MSS connected to a load, where the system available capacity (SAC) and hourly system load (HSL) are shown in fig.3. The behavior of SAC curve shows that the generating system follows several states. These states can involve partial or total failure of a simple unit or of several units. The appearance of dips in the same curve reflects units' breakdowns and the resumption to the initial level of capacity indicates that repairs were made. The shaded area under the curve indicates the energy not supplied (ENS) and their corresponding time intervals denote durations where the consumption exceeded the production. They learn about the times when the expected production is actually not available in its entirety. If the study period is 24 hours, we will talk about the unavailability of the system for about 3 hours. Each decreasing in the SAC curve behavior corresponds to a degrading state, subsequently to a decreasing level of system reliability.

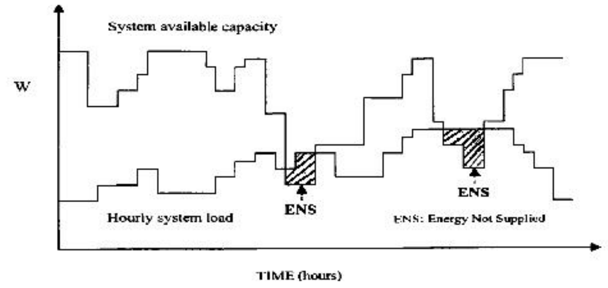

Figure 3. Superimposition of the system available capacity and the load model

Load points are linked to supply resources by electric lines that have their own physic characteristics. The increasing of demand implies: the increasing of the current transit, the decreasing of voltage level, the increasing of reactive power consumption and etc. After the activation of system defense (compensators), regarding physic characteristics of lines, when thresholds values are reached, the protections operate and isolate the line. If the studied system is in looped configuration (supposed more reliable and more flexible in faults conditions), there is a load transfer to another line which at its turn becomes loaded and the line opening's scenario is repeated leading to cascade degradation in the lines of the system. The final results become the loss of load. Another scenario is probable; it is the luck of coordination between the items in the system defense. The problem stay in the physics category and the system loading can deal to voltage and frequency collapses. The persistence of the phenomena during a lap's time causes generating units stopping or stall. These are scenarios of several blackouts. When a failure occurs in generating units, the standby units are connected and activated. If their contribution is insufficient, the supply becomes lower than the consumption. When the polar angle of the engine reaches a certain threshold, they drop and consequently we have loss of load independently on the reliability of the connection between the supply system and the load point.

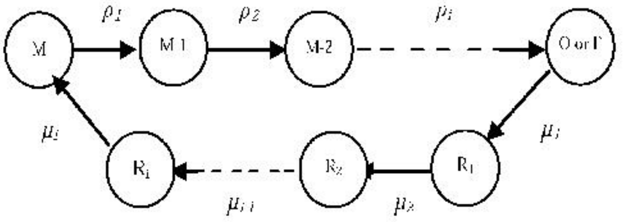

Figure 4. Degradation State transition: degradation tripping vs. restoration

III. RESTORATION PROCESSES MODELING

A. *case of conventional system*

The network reconstruction after the blackout is modeled using Markov chain method as given in Fig 4 where the degradation states are inspired from fig.2.

ρ_i , i=1,n are degradation transition rates
μ_i , i=1,m are restoration rates

The main objective of the restoration service is to minimize the number of customers faced with the interruption of power delivery by transferring them to support feeders via network reconfiguration, with respect to components operational constraints. The reaction time is a pertinent factor to take into account where disconnected areas should be restored as quickly as possible. This scenario could be considered in the case of the integration of smart grid.

B. *Case of a smarter system*

It will be better to simulate events which will occur in the case where smart systems are integrated in the power grid. Three scenarios are discussed in the following.

- Scenario 01: the initiating event is the peak demand

The smart grid concept uses smart metering which is designed to manage consumption used at peak times by encouraging more off peak power by households and small businesses, therefore shifting the load. Most outage management system and distribution management system (OMS/DMS) analyze and optimize network performance and reactively determine outage locations. Smart grid algorithms that incorporate spatial analysis will be part of a decision support system that can help determine risk and potential customer impact and recommend preventive measures by integrating real time weather monitoring system (WMS). Note that this scenario is similar to the 2003, USA blackout.

- Scenario 02: the event is already happen due to a loss of generator

This scenario is similar to the Algerian blackout (2003). The loss of generator coupled to a period of peak demand lead to a cascading event and finishes to a blackout. Smart grid via sensors and intelligent devices could avoid this undesired event by:

Integrating more renewable energy power sources to the power transmission and distribution systems. They will relieve stress by adjusting automatically their operation. Then, smart grid could switch to solar and wind mode (or energy storage) to mitigate peaks demand.

Deciding to shed appropriate system load by temporarily switching off distribution of energy to different geographical area proportional to the severity of power system disturbance.

- Scenario 03: the system is in a states O or F of figure 03.

Smart grid coordinates units, loads, transmission system, and their associated characteristics to a fast restoration of power to consumer by establishing priorities. By using location intelligence capabilities, it quickly diagnoses outages and determine the location of a fault caused by physical damage of the transmission and distribution facilities due to weather by measuring the optical distance along the fiber.

IV. DECISION MAKING UNDER UNCERTAINTY

In general, for consumer goods, the effect of the actions performance is immediate. However, in the case of electricity, it has certain inertia, because the measures to be taken to improve performances are heavy. They concern the integration of smart grids and the insertion of renewable energy sources.

Regarding this issue, two main aspects directly connected are the cost and the uncertainty. The dual objective tracked in this work must go through two essential components, such as: the evaluation of costs to conduct operations performed either separately or collectively, and the evaluation of the involvement of key stakeholders, namely: decision makers and consumers. Using cost benefit analysis method, the objective function expressed as a total cost is formulated and gathering investment expenses and losses cost. The total cost is calculated each time that an action is considered on the network. Regarding the game matrix, the rows correspond to scenarios of satisfaction and the engagements of the customers, however, the columns correspond to the strategies developed by the decision makers. The elements of the game matrix are alternatives costs. The most common decision making criteria adopted by the game theory are: Laplace-Bayes criterion, Wald or maxi-min criterion, Savage or mini-max Regret criterion and Hurwitz criteria [7].

CONCLUSION

In a grid, even if the transportation and distribution parts are highly reliable, if the production units fail, the whole system collapses. When the load demand exceeds the production capacity, there is loss of load. To determine its proportion of time, we use loss of load probability model. A smarter power grid could be the solution to these woes. This new technologies highlight the following features: Ability to perform forecast peak demand and to ensure its management, anticipation of the start of the emergency; risk assessment of equipment failures; management of shedding their workforce at the appropriate times and select the consumer prior to relieve via current carriers. This new technologies and concepts can significantly reduce barriers to the integration of renewable resources. It aims to build smart renewable-energy generation using micro-grids to enable houses, buildings, and villages to be energy self-sufficient.

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***Operational Research Department, University of Bejaia, Algeria, 06000
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