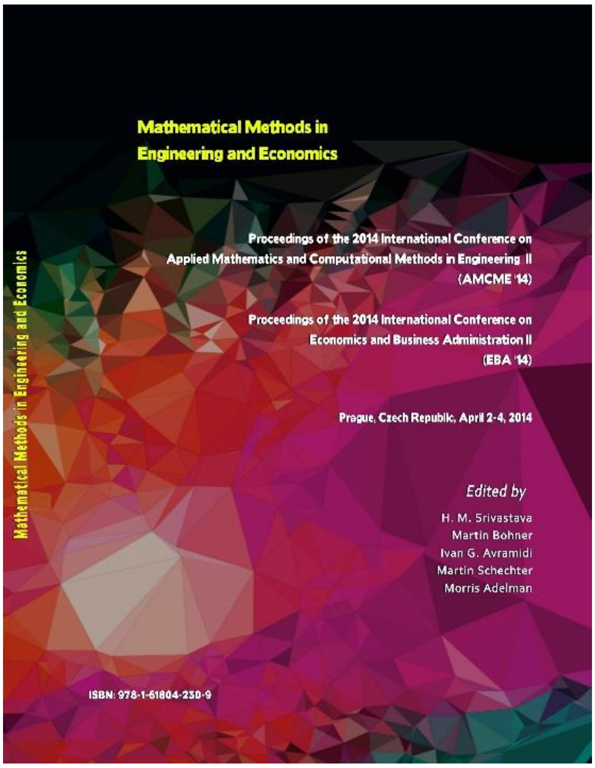

ARMA models for blackouts forecasting and Markov method for interruption modelling in electrical power systems

Iberraken Fairouz, Medjoudj Rabah, Aissani Djamil and Klaus Dieter Haim

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Index Terms— **ARMA models, blackouts, interruption modeling, renewable energy, smart grid.**

I. Introduction

Traditionally, the research and the development of reliability analysis methods have focused on the generation and the transmission part of the electric power systems. Due to economic factors, they are commonly run near their operational limits. Majors cascading disturbances of blackouts of the transmission systems have various consequences. From reliability point of view, these events demonstrate that operating practices, regulatory policies, and technological tools for dealing the changes are not yet in place to assure an acceptable level of reliability. This paper investigates the contribution of the integration of the technologies of information and communication combined to the insertion of renewable energy resources giving birth to a smart energy grid. These smart systems allow mitigating these cascading events, from one hand and accelerating the network reconstruction in the case where those events were not prevented, from the other hand. Very far in the past, the issue of blackouts was introduced in biomedical engineering, where researchers have defined a blackout as loss of vision [1]. Effectively, the definition regarding the electrical engineering studies is not so far as it means the loss of light. A typical large blackout has an initial disturbance or trigger events followed by a sequence of cascading events [2]. The progression of blackout can be divided into several steps, such as: precondition, initiating events, cascade events, final state and restoration. Among these five steps, cascade events can be further divided into three phases in the process of some blackouts [3]-[4]: steady-state progression, triggering events and high-speed cascade. Karamitsos and Orfanidis [5] enumerate different causes of blackouts occurrence using several structures of networks. They have used power flow techniques to model the behavior of the systems and have stated that the frequency and the size of the blackouts depend weakly on the topology of the network and their distribution is a weak function of the latter. For some authors, suggesting some approaches, it is possible to understand and to control blackouts [6]. The authors have analyzed a 15 years, of North American electric power system blackouts for evidence of self-organized criticality. They have proposed three measures tools, such as: the energy unserved in MWh, the amount of power losses in MW and the number of customers affected. They have given the proportion of the contribution of weather in blackouts occurrence, estimated to 50% of the total number. This phenomenon takes into account the intensive operation of both cooling and heating systems. To reduce the risk of major blackouts trough improved power system visualization, Overbye and Wiegmann [7] describe several visualization techniques that can be used to provide information and control at time using automation system. They have stated that it is possible to mitigate blackouts through corrective and extreme control; such as: quickly load shedding at right location and opening tie-lines. Many researchers were interested in the problem of blackouts, and more works were conducted on the deterministic side. Nevertheless, the stochastic aspect has been addressed with the introduction of several probabilistic models highlighting the risk of blackouts occurrence. To our knowledge, the forecast aspect has not been addressed, and it is in this context that we make a modest contribution; it is to show the tendency of the evolution of these events dreaded by both energy distributors and consumers. The work reported in this paper was made by a research team specialized in electrical engineering reliability (FSE2) of the research unit LaMOS from the University of Bejaia, Algeria. After reviewing about 200 works on the blackouts, and based on the synthesis work conducted by the IEEE PES

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Task Force [8] and while having ideas about what can make smart systems, we have introduced forecast models to show the evolution of the latter in the future and to predict the behavior of the conventional network if ever information systems are integrated and in the case it becomes better communicating.

Using box and Jenkins models for North American blackouts forecasting, where the trend is quite constant, we have demonstrated that the ICT integration performs both power system operation and some reliability indices. With smart meters, a smart grid is able to collect real-time information about grid operations, through a reliable communication networks deployed in parallel to the power transmission and distribution systems.

The occurrence of a blackout can be modeled using the Markov method. A competing failure process is proposed gathering the degradation process (due to the normal operation of the system subject to ageing and to the wear of equipment) and the shock process (due to the loss a generator or a main line). Based on the three experiences of the Algerian, Italian and American blackouts occurred in year 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. A particular interest is given to the contribution of both integration of smart systems and insertion of renewable sources to better manage the peaks of demands, to reduce power losses and to increase the availability of electricity. The achievements of these goals depend on the engagement of managers and the comprehension of customers to adopt the decisions. This issue can be investigated using economic criteria inspired from game theory as developed recently by Medjoudj et al [9]. Several countries have already taken a step ahead in the field of smart grids integration in the contexts of sustainable development and the insurance of the security of energy supply. The rest of the paper is organized as follows: section 2 is devoted to time series modelling, using Box and Jenkins method. In section 3 a particular attention is given to cascade degradation processes modeling where we have introduced competing failure processes including both degradation and a shock processes. In the case of a blackout occurrence, a particular interest should be granted to the restoration process. This issue is developed in section 4 with applications for three special cases of blackouts occurred in year 2003. In section 5, we have judged interesting to think creatively to produce technical measures to develop some societal indicators in conjunction with smart systems to mitigate blackouts, as a future work. Section 6, is devoted to conclusion and discussions.

II. TIME SERIES MODELLING

There are two types of models to account for time series. Initial works consider that the data is a function of time $y = f(t)$. This category model can be adjusted by the least squares method, or other iterative methods. The model analysis by Fourier transform is a sophisticated version of this type of model. A second class of models seeks to determine the value of each series based values which proceed $y_t = f(y_{i-1}, y_{i-2}, ...)$. This is the case of ARIMA models (Auto-Regressive - Integrated -. Moving Average), this class of models has been popularized and formalized by Box and Jenkins [10].

A. Main time series models building

A time series is a chronological sequence of observations on a particular variable. Usually the observations are taken at regular intervals (days, months, years). A time series analysis consists of two steps: (1) building a model that represents a time series, and (2) using the model to predict (forecast) future values. For our studies, we introduce the following models:

1) ARMA models: The general Auto-Regressive Moving Average (ARMA (p,q)) model for a univariate stationary time series can be presented analytically as:

$$Y_t = \phi_1 Y_{t-1} + \phi_2 Y_{t-2} + ... + \phi_p Y_{t-p} + u_t + \theta_1 u_{t-1} + \theta_2 u_{t-2} + ... + \theta_q u_{t-q} \quad (1)$$

Where: ϕ and θ are polynomial functions of degrees p and q respectively. It is a combination of two processes such as: Auto-Regressive and Moving Average. The autoregressive components represent the memory of the process for the preceding observations. This model can be presented as follows:

$$Y_t = \phi_1 Y_{t-1} + \phi_2 Y_{t-2} + ...\phi_p Y_{t-p} + u_t \quad (2)$$

The moving average components represent the memory of the process for preceding random shocks. It can be formulated as:

$$Y_t = u_t + \theta_1 u_{t-1} + \theta_2 u_{t-2} + ... + \theta_q u_{t-q} \quad (3)$$

2) ARIMA models: A no stationary series is provided by the ARIMA (p,d,q) processes, it has the general form:

$$\Delta^d Y_t (1 - \phi_1 L - \phi_2 L^2 - ... - \phi_p L^p) = (1 - \theta_1 L - \theta_2 L^2 - ... - \theta_p L^q) u_t \quad (4)$$

3) SARIMA models: We use the Seasonal Autoregressive Integrated Moving Average processes when we have to deal

with time series with trends, seasonal pattern and short time correlations.
If we denote:
- Y_t, The number of events passing through the observed link during the time interval $[(t-1)\Delta\,;\,t\Delta]$ of duration $\Delta > 0$ for t=0,1,2,…
- B, the backshift operator which affects the time series y_t given by $(B^d y)_t = y_{t-d}$ for al integers d.

The $SARIMA(p,d,q)\times(P,D,Q)_s$ process y_t is given by the following equation:

$$\phi_p(B)\Phi_P(B^s)(1-B)^d(1-B^s)^D y_t = \theta_q(B)\Theta_Q(B^s)\varepsilon_t \quad (5)$$

Where: ε_t is a white noise sequence, Φ and Θ are polynomial functions of degrees P and Q respectively.

B. Forecasting time series

In general Box and Jenkins have popularized a three-stage method aimed at selecting an appropriate (parsimonious) ARIMA model for the purpose of estimating and forecasting a univariate time series. The three stages are: (a) identification, (b) estimation, and (c) diagnostic checking.
1) *Model Identification:* A comparison between Auto-Correlation Function (ACF) and Partial Auto-Correlation Function (PACF) samples with those of various theoretical ARIMA processes may suggest several plausible models.
If the series is non-stationary the ACF of the series will not die down or show signs of decay at all. If data are non-stationary, transformations are required to achieve stationarity. The time series differentiation is involved to remove the trend and the seasonal trends. It is often considered the following operations:

The first difference: $z_t = (y_t - y_{t-1})$

The second difference: $z_t = (y_t - y_{t-1}) - (y_{t-1} - y_{t-2})$

From the other hand, we can consider a Log transformation to handle the exponential growth of the series and to stabilize their variability.
Once we have reached stationarity, the next step is the identification of the p and q orders of the ARIMA model. Model Estimation: *In this second stage, the estimated models are compared using Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC).* Model Validation: *In this stage we examine the goodness of fit of the model. We must be careful here to avoid over fitting (the procedure of adding another coefficient is appropriate). The special statistic tests we use here are the Box-Piece statistic (BP) and the Ljung-Box (LB) Q-statistic, ones which serve to test for autocorrelations of the residuals.*

C. *Real cases applications*

In this paper we have made two applications using Box and Jenkins analysis and forecasting and where the dominance of ARMA model is demonstrated.

1) Forecasting the number of blackouts of northern USA

The phenomenon which binds several countries in the field of power systems is the blackout. Just look at the spectacular events of 2003, where Algeria has shared the same adventure with the Italians and Americans. America is very striking this phenomenon because it is repetitive and a database has been created in this way, and where several research works have exploited it. To this end, we wanted to use it to establish forecasting models. We have reported the events as an original time series plot in figure 1.

We can see from this plot that there seems to be seasonal variation. So we need to introduce the differentiation of the series. Both of ACF and PACF show a single spike at the first lag. An ARMA (1, 1) model is indicated. The analysis of the autocorrelation coefficients and the partial autocorrelation of the transformed series bring up a significant peak delay 1 for the autocorrelation peak and a significant delay 2 for the partial autocorrelation. Based on these results, we propose as a possible model SARIMA (1,0,1) $(1,1,2)_4$. The estimated model is given as follows.

$$Y_t = 0.9560\,Y_{t+1} - 0.8694\,Y_{t-6} - \varepsilon_t + 0.7638\,\varepsilon_{t-1} + 0.9999\,\varepsilon_{t-4}$$

The forecasting values are shown in the plot of the figure 2, where the behavior of the future events seems to be constant, thanks to the integration of smart systems in the American power network. This country has a great advance in the development of ICT, and it is oriented towards the reliability issue and to mitigate these dreaded events.

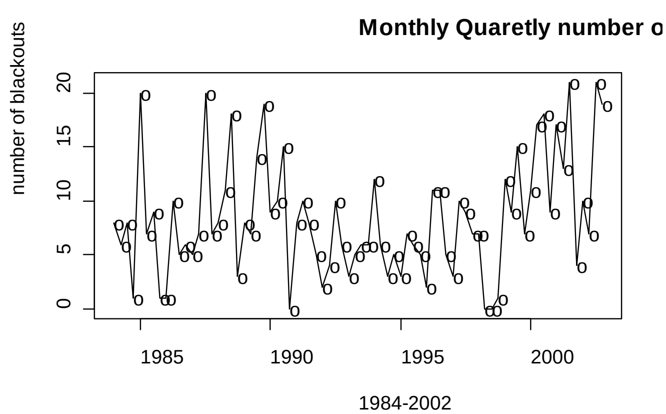

Fig. 1. Plot of the Original series

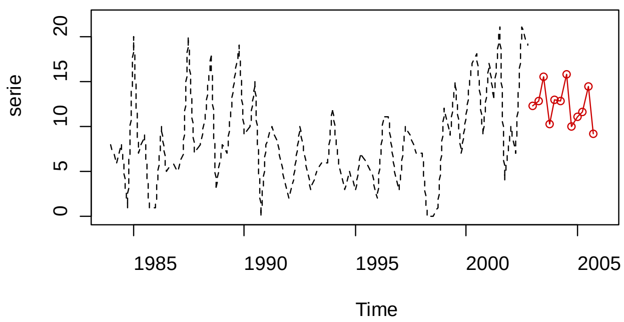

Fig. 2. Result of forecasting

2) Forecasting failures of components of an electrical distribution network

As stated in several recent publications, 90% of the total failures are recorded in the distribution part. It is essential to recall that actually power systems are modelled as both multi-components and multi-degraded systems. It is useful to distinguish and to classify failures based on their origins and by the components it concern. To this end, using Box and Jenkins method, we formulate forecasting models for such equipment of the Bejaia city, (Algeria) distribution system, as follows:

- overhead lines forecasting failures model

$$Y_t = 0.34851 Y_{t-1} + 0.77956 Y_{t-2} + 0.83544\, \varepsilon_{t-1} + \varepsilon_t$$

- underground cables forecasting failure models

$$Y_t = 0.29148 Y_{t-1} + 0.83538 Y_{t-2} + 0.85063\, \varepsilon_{t-1} + \varepsilon_t$$

- joint nodes forecasting failures model

$$Y_t = 1.01066 Y_{t-1} + 0.06623 Y_{t-2} + 0.33257\, \varepsilon_{t-1} + \varepsilon_t$$

- MV/LV sub-station forecasting failures models

$$Y_t = 0.04987 Y_{t-1} + 0.75822 Y_{t-2} + \varepsilon_t$$

- Mean voltage feeder forecasting failures model

$$Y_t = 0.30520 Y_{t-1} + 0.21176 Y_{t-2} + 0.30099 Y_{t-3} + \varepsilon_t$$

The time series analysis was done on annual intervals and the data were collected on a period of ten years. The models are generally ARMA (p, q) and the forecasts show that failure evolve in increasing manner with the exception of the last two years due to the renewal of some ageing sections of cables during the recent years.

III. CASCADE 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 ageing, 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 3.

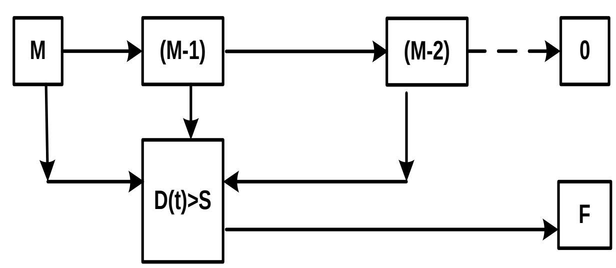

Fig. 3. System states diagram subject to two failures processes where M, (M-1), are degradation states,O is a degradation failure state and F is a catastrophic failure state.

Let us consider a repairable system connected to a load, where the system available capacity (SAC) and hourly system load (HSL) are shown in figure 4 [11].

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

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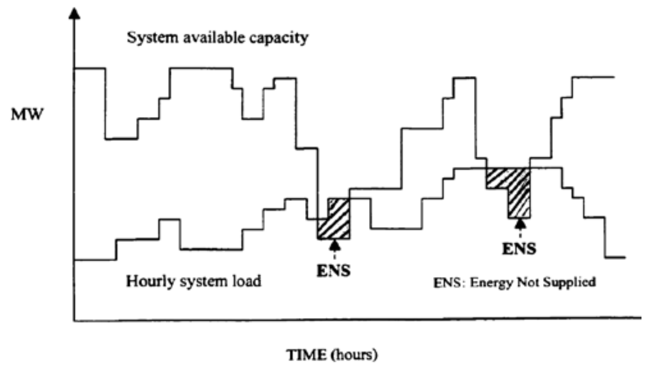

Fig. 4. Superimposition of the system available capacity and the load model

corresponds to a degrading state, subsequently to a decreasing level of system reliability. 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.

IV. Restoration Processes Modeling

A. Case of a conventional system

The network reconstruction after the blackout is modeled using Markov chain method as given in figure 5 where the degradation states are inspired from figure 2. Each state corresponds to a special structure of the network and to particular values of voltage and frequency.

As it is not easy to master the occurrence of the blackout in the current state of the network, we have attempted to model the network restoration while suggesting the contribution of smart systems in the acceleration of the service restoration process. To this end, we have studied two cases occurred in year 2003, namely the Algerian and the Italian blackouts. A particular interest was paid to the following parameters, such as: the restoration rate, the partial power restored at each stage and finaly the cumulative power restored at each stage. The tables 1 and 2 were filled following the stages of the figure 5, where the R_i are the restoration states with i=6 for the Algerian case and i=5 for the Italian one. We difined the used parameters as: $\rho_i, i=1,n$ are degradation transition rates, and

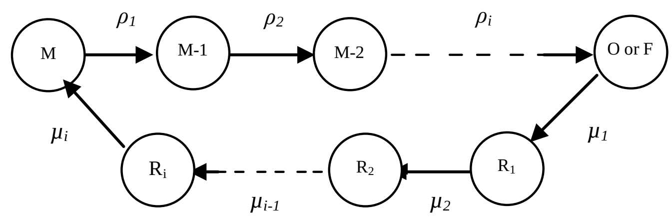

Fig. 5. Transition state diagramm: degradation tripping vs. restoration

$\mu_i, i=1,m$ are restoration rates.

In a general manner, we have observed an inertia in the restoration processes of the networks but it is more apparent in the Algerian case. The first information about the results show a lack of effective measures for a fast restoration. To highlight the attributes of smart systems integration regarding the three countries affected by the blackouts of 2003, we have developed a comparison presented in table 3. We deduce that the order of effectiveness is decreasing according to the classification as follows: USA, Italy and Algeria because the USA had firstly integrated the smart system in their conventional network to increase the reliability and the security of supply. The Italian network behavior is acceptable, however Algeria, can take this opportunity to learn from the two experiences.

The main objective of the restoration service is to minimize the number of customers faced with the

TABLE I
STATE RESTORATION IN CASE OF 2003 ALGERIAN BLACKOUT

States	0	1	2	3	4	5
μ(s^{-1})	0.15e-4	5.0e-4	4.2e-4	2e-4	2.2e-4	2.7e-4
Restored power (%)	15	15	30	13.6	23.3	3.4
Total restored power (%)	15	30	60	73.3	96.6	100

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TABLE II
STATE RESTORATION IN CASE OF 2003 ITALIAN BLACKOUT

States	0	1	2	3	4
$\mu(s^{-1})$	4.0e-5	7.9e-5	6.9e-5	5.0e-5	6.0e-5
Restored power (%)	5	40	25	20	10
Total restored power (%)	5	45	70	90	100

TABLE III
PARAMETERS COMPARISON BETWEEN ALGERIAN, ITALIAN AND USA BLACKOUTS

	Algeria	Italy	USA
Power restored(GW)	5.003	27	61.8
Total restoration time(s)	15960	43200	104400

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.

1) *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 determining 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.

2) *Scenario 02: the event has already happened due to a loss of a component*

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.

3) *Scenario 03: the system is in a state O or F of figure 3.*

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.

V. CREATIVE THINKING FOR FUTURE WORK

Creativity is essentially the act of an individual. It can come solely from within or it can be generated by a team working together in such a way that a team consciousness arises to which the individual members constitute [12]-[13].

A. *Presentation of problem*

In times of peak demand, in the case of insufficient of power availability in a region or in a locality, in the case of fear that automation does not manage the power flow and to be in a blackout situation, the electricity distribution company shall do shedding of a part of the load. The relevant question is which entity will be relieved?

Firstly, in such situations, contrary to popular belief where the priority of the availability of electrical power supplied by a grid was given to hospitals, industrial production units and authorities, we present an alternative management vision by reviewing in depth the assignment order of these priorities.

B) Proposition

It escapes to no one that earlier cited entities are equipped with backup sources during the design of the projects , therefore from moral point of view , we see that the high priorities are given to those who are not in need. From an economic point of view, it is necessary to help those who do not have a secure delivery. The question is how to manage load shedding with the emergency source?

- It is imperative that the energy distributor has an updated file of customers equipped with emergency sources.
- The network should be more communicative, and in real time.

- Load shedding and network automation must be functional. The harmonics are often seen as a problem in the provided power quality. However, nowadays, it is a boon in the field of communication and data transfer. This is to address the notion of power lines, which are already operating in the field of television and internet in home networks. Regarding smart management of electrical distribution networks, we proposed the concept managing the schedules of openings and closures of protections at the upstream of the customer installation by the energy dispatchers from one hand and enabling connection of decentralized renewable energy resources to the transmission or to the production electricity networks. This solution can help to mitigate blackouts by injecting power in time when needed instantaneously.

VI. Conclusion and discussions

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 power lines concept. 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. In the literature, it gave us to see the lack of research works in stochastic modeling of the occurrence of blackouts. To highlight our competence in the forecast, we introduced other opportunities of modeling using the concept of Box and Jenkins. We were able to prove the dominance of ARMA models in the field of energy distribution. Also in this context, the integration of smart system into the conventional one can help to exploit the weather forecasts to predict changes in consumer demand and anticipate on the main technical and organization measures. As it is necessary to consider the decentralization of the production units and encourage maintenance actions on the clean energy production units considered obsolete. Another aspect that is relevant is the provision of emergency sources of energy by the distributor and not by the customer. It was demonstrated that this decision contribute to avoid moral prejudice often felt by the customer and the financial one often sustained and supported par the distributor of the energy. Finally, the studies done on individual cases can be generalized to all entities throughout the national territory.

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ARMA models for blackouts forecasting and Markov method for interruption modelling in electrical power systems

Iberraken Fairouz, Medjoudj Rabah, Aissani Djamil and Klaus Dieter Haim

Abstract— **Customers' requirements in terms of availability of supply and quality of energy are increasingly growing and the electricity distribution utilities are asked to meet them and to provide a high quality of service. They are required to activate in a multidisciplinary area including the mastery of data acquisition and processing, secured information transfer and an easy communication mode with customers. This paper aims to provide knowledge and to think creatively to assist decision-makers to understand the impacts of information and communication technologies (ICT) integration in the conventional power network giving birth to a smart energy grid. We have also investigated the attributes of combining smart systems integration with renewable energy resources insertion to mitigate the occurrence of cascading events such as blackouts. The basic tool of our work is the mastery of time series analysis and the forecasting models. This work is an excellent opportunity to highlight the dominance of ARMA model in forecasts and that of the Markov model in interruptions modelling in the field of reliability evaluation of electrical networks.**

Index Terms— **ARMA models, blackouts, interruption modeling, renewable energy, smart grid.**