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Power System Simulation Model Based on Probability Analysis

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ABSTRACT: *By virtue of the vital nature of electric power, both to our economic and personal well being, a power system is expected to supply electrical energy as economically as possible, and with a high degree of quality and reliability. The developing countries in general place higher reliability standard on the performance of electricity supply. However, there has been no significant study in the context of the Nigeria power sector to power system simulation model based on probability analysis the technical appraisal of the state power systems in general is confined to examining the Plant Load Factor (PLF) as a measure of capacity utilization only. The present study is a modest attempt to evaluate the reliability of the Nigeria power system in the framework of a theory-informed methodology power system simulation model based on probability analysis.*

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INTRODUCTION

Electric power is vital to both our economic and personal well – being and hence a power system is expected to supply electrical energy as economically as possible, and with a high degree of quality and reliability. In fact, few products have a greater need for quality and reliability. Reliability in its broad sense refers to the probability that a component or system comprising components is able to perform its intended function satisfactorily during a specified period of time under normal operating condition. Thus the reliability assessment of power system in mainly concerned with its capability, which is related to the existence and availability of sufficient facilities to satisfy customer load. The basic facilities of a system are in the three sectors of its function, viz, generation, transmission and distribution, which are usually vertically integrated. Electric power produced at the generation end is carried to the consumers via transmission and distribution facilities. In this paper our focus is only on the generation sector. A modern power system is very large and composed of n power generating stations, where power is generated from fuels by hydroelectric stations. Each generating station or plant consists of M plant units or generators, each with a rated capacity. Each of the N stations has an installed capacity, K megawatts (mw), which is the sum of the rated capacities of its M units, and the system installed case of a hydropower system, each power station has usually associated with it a big reservoir behind a dam that supplies hydraulic power to drive each of the M generators. A power system is unique in that its product is on that must be generated the instant its service is demanded. Another significant characteristic is the demand for electricity varies greatly at random according to the time of the day and the season of the year. Therefore a power system is designed to supply instantaneously the power demanded by consumers.

However, failures in the system of occur when demand exceeds supply as in the case of any other goods and services. Demand can exceed supply for two main reasons. On is the random deviation of the demand from its expected level such that a very high peak demand exceeds the installed capacity of the system. Capacity of a power system is in general determined after taking due consideration of such unforeseen fluctuations in demand. This is effected by means of reserve or standby capacity over and above the expected peak demand that is to a be met.

Shortage may still occur even if the load is not far from its expectation; a high demand that does not exceed the installed capacity of the system can exceed the available capacity at that moment. This is due to generator deratings, scheduled preventive maintenance and forced outages of generators. Generator deratings result from equipment problems and changes in operating conditions, and are a function of the age of the equipment. Outage refers to a certain state of a unit when it becomes unavailable to perform its intended function due to some event directly associated with it. An outage may be either a scheduled one or a forced one. Scheduled outage (or maintenance outage) is a planned event, whereby a component/ unit is deliberately taken out of service at a chosen time form preventive maintenance or overhaul or repair; this is to keep the generating units in proper running condition. Forced outage, on the other hand, results when a unit falls out of service due solely to random events such as breakdown, malfunction of equipment, etc.

In the case of a hydropower system, besides these two scenarios, shortage can still occur if the hydraulic power in any storage is not sufficient to turn the concerned generator. The plant unit is then shut down, and the system capacity falls accordingly. A modest attempt is made in this paper to evaluate the reliability of the Nigeria system. Following a detailed discussion of the methodology used in this study, the maximum likelihood estimates of availability and forced outage rates as well as loss of load probability measures are calculated for the 10 hydropower plants of Kerala. Power system simulation model based on probability analysis

AVAILABILITY AND OUTAGE MEASURES

In a Nigeria process, the life history of a repairable electric power system component during its useful life period is represented by a two – state model, the two possible state being labeled ‘up’ or ‘functioning’ and ‘down’ or ‘unavailable’ denoted by 1 and 0 respectively. Thus when the component fails, it is said to undergo a transition from the up to the down state, and conversely, when repairs are over, it is said to return from the down to the up state. This idea than facilitates to interpret the concept of reliability in terms of the fraction of the total time the component remains in the up state. The length of functioning period if also referred to as the time to failure, and the period under repair as the downtime. The probabilistic approach to power system reliability analysis views the system as a stochastic process evolving over time. At any moment the system may change from one state to another because of events such as component outage or planned maintenance. Corresponding to a pair of state, say (i,j), there is a conditional probability of transition from the state i to the j. Suppose the performance of a power plant is continuously monitored to record the sequence of failures and repairs during sustained operation in order to assess its performance. During each failure – repair cycle, the time to failure (when the plant is in upstate) and the time to repair (when the plant is in down state) are recorded. The number of failures per unit of time is known as the failure (or hazard) rate, and the number of repair per unit of time, the repair rate. The reliability of a power plant is often measured in terms of two availability indices, viz, instantaneous availability, A (t), and steady – state (long – run) availability, A (∞). The former refers to the probability that the power plant is available for operation at any time t and the latter to its arability for large values of t, that is, in long run. Thus,

A (t) = prob (available at time t,) and
A (∞) = lim A(t).
t → ∞

The first step in an availability study is to specify certain probability models for the two variables, time – to – failure, denoted by X and time – to – repair, denoted Y. the second step is the derivation of the availability indices, which in general are the function of the parameters of the statistical models specified for X and Y. Usually the failure and repair rates are assumed to be constant; this leads to the assumption the time – to – failure and the time- to repair variables follow exponential distribution. The exponential distribution is one of the two (the other being the geometric distribution) unique distributions with the memory less or no – property. That is future lifetime of a component remains the same irrespective of its previous use, if its lifetime distribution is exponential. Thus we assume that the time – to – failure, X, is an exponential variable with parameter λ, so that its density function, viz, failure (hazard) density function, f (x), is given by f(x), $\frac{1}{\lambda}\exp\left(\frac{-x}{\lambda}\right)$ for x > 0. The parameter 1 / λ is the constant failure (hazard) rate for an exponential distribution of the above form, the mean if given by λ. Hence the meantime – to- failure (MTTF) of the power plant is equal to λ; this is also known as the expected survival time. The probability of a plant surviving at time t in a constant failure rate environment i.e. its survival function, denoted by R(t), is then obtained by integrating the failure density function, f(x), and is given by R(t) – exp (-x/λ). The complement of this survival probability of failure in time t, given by 1 – exp(-x/λ). D varies between 0 for immobility (lest propensity to down) and I for extreme propensity to down.

CAPACITY OUTAGE DISTRIBUTION

The next step in the generation reliability model is to combine the capacity and availability of the individual units to estimate expected available generation capacity in the system. Thus we obtain a capacity model; in which each generating unit is represented by its nominal capacity Kj and its for, Rj = 1 …. N. Not that for each of the N units the generating station, the expected available capacity $k^A_{j,}$ - 1…..N, is a random variable that can take the value 0 with probability Rj and the value kj with probability Aj= 1 Rj as show below:

k^A_i ($k_{i.}R_i$) $\{$ $(kj, Aj = 1 - Rj)$, if unit is available;

$(0, Rj)$, if unit is in outage.

Then the expected available capacity of a plant unit j is k_jA_j and the expected total generating capacity available at the plant level is: $K^{A} = \sum_{j}^{N} K^{A}{}_{j}$ = kjAj and the expected total generating capacity available at the plant level is: $K^{A} \quad \sum_{j}^{N} K^{A}{}_{j.}$

Capacity state			Plant Availability
All up I up, I down	Unit 1	Unit 2	A_iA_2
	Up Up Down	Up Down Up	A_1R_2+ $A_2R_{1=}$ $A_1R_2+A_2R_1$
All down	Down	Down	R_1R_2

Note that the available capacity at both the unit $k^{A}{}_{j}$ and the plant level k^{A} is a random variable; and the units fail and get repaired independently of such events of other units. These conditions help us obtain the probability distribution of K^{A} by combining the independent individual probabilities of k_j^{A}. This in turn gives us a discrete (available) capacity distribution $K^{A} = (k_{i,} R_j)$ I = 1,….2^{N}. The available capacity states takes on 2^{N} values, equal to the number of combination of up and down units (due to forced outages) in an N- unit system. Each capacity state represents an outage event with one or more Units unavailable. The capacity probability distribution is tabulated and referred to as the capacity outage probability table. The capacity of ith state, Ki with M available units and N – M failed units is the sum of the capacities of the M available units, this is,

$$K_i = K_i + K_2 + \ldots\ldots\ldots + K_M$$

Given the outage or availability probabilities, the probability corresponding to each available capacity state can be calculated. Remember that the probability f the simultaneous occurrence of two or more independent events is the product of the respective event probabilities. Thus the probability of the ith state is equal to the product of the availabilities A_i of the M available units and the FOR_s R_i of the N – M out – of – service units that is:

$$P_i = A_1A_2 \ldots\ldots A_M R_1R_{2\ldots\ldots\ldots}R_{N\ldots\ldots\ldots M.}$$

For illustration, below we give that capacity outage probability table for a 2-unit and 3- unit plants and their generalization:

Case of a 2- unit plant

Note: $R_j = 1 - A_j$ is the FOR and A_j is the steady state availability of unitj.

1. Case of a 3 – unit plant
   Note: R_j =1- A_j is the FOR and A_j is the steady state availability of unit j.

Capacity state				Plant Availability
All up I up, I down	Unit 1	Unit 2	Unit 3	$A_iA_2A_3$
	Up	Up	Up	$A_1 A_2 R_3+$
	Up	Up	Down	
	Up	Down	Up	$A_2R_1A_{3+}$
	Down	Up	Up	
				$A_1 A_2 R_3+A_1R_2 A_3+R_1A_2A_3$
	Up			$A_1 R_2R_3+$
1 up, 2 Down	Down	Down	Down	$R_1A_2R_3+$
	Down	Up	Down	$R_1R_2A_{3=}$
		Down	up	$A_1 R_2 R_3+R_1A_2 R_3+R_1R_2A_3$
				$R_1R_2R_3$
	Down	Down	Down	

I general,
Plant availability (capacity state probability, Pj) when all plant units are up – II A_j for all j. for a 2 – unit plant, when 1 unit is up and 1 unit down = $\sum$ $A_j(1-A_j)$; i, j = 1,2. For a 3 – unit plant, when 2 unit are up and 1 unit down= $\sum$ $A_i A_j(1-A_k)$; i, j,k =1,2,3.
For a 3 – unit plant, when 2 units are down and 1 unit up = $\sum$ $A_i(1-A_j)$; i, j,k =1,2,3.

POWER SYSTEM SIMULATION MODELS

Power system simulation involves modeling power generation equipment, planning the integration of power plants onto the electrical grid, and performing generator control system parameter estimation. Power system simulation models is computer simulation programs like MATLAB and simulink that allows the user to perform critical power system simulation and optimization task such as

1* Simulating performance against gndcode and ensuring production goals are meet.

2* Automating control system parameter estimation to meet regulatory requirement
3* Performing EMT simulation and harmonic analysis to identify and mitigate power quality issues examples

- Modeling wind power and integration ‘
- Modeling and simulation of PV solar power inverters
- Parameter estimation
- Hydro Quebec models wind power plant performance.
- Hydro Quebec large scale meets time simulation of wind power plant.

Power system simulation models in also a class also of computer simulation program

(MATLAB and simulink) that focus on the operation of electrical power system that uses a wide range of planning and operational situation which include

- Long–term generation and transmission expansion planning
- Short–term operational simulation
- Market analysis (e.g. price for casting)

The key elements of power system that are model includes

1. Bad flow (power flow study)
2. short circuit
3. transient stability
4. optimal dispatch of generating units (Unit commitment)
5. transmission (optimal power flow)

1. **Land Flow Calculation:** Load flow calculation is the most common network Analysis tool for examining the undisturbed and disturbed network within the scope of operational and strategically planning. The load – flow calculation can provide voltage profiles for al nodes and loading of network component, such as scales and transformers, with this information, compliance to operating limitations such as those stipulated by voltage ranged and maximum loads can be examined. This is for example; important for deterring the transmission capacity of underground cables, where the influence of cable bounding on the load capability of each cable has to be taken also into account. Due to the ability to determine losses and reactive power allocation, load- flow calculation also supports the planning engineer on the investigation of the most economical operation mode of the network.
2. **Short Circuit Analysis**: Short circuit analysis analyzes the power flow after a fault occurs in a power network. The fault may be three-phase short circuit, one-phase grounded, two-phase short circuit two-phase grounded, one-phase break, two-phase break or complex faults.
3. **Transient Stability Simulation:** The goal of transient stability simulation of power system is to analysis the stability of a power system in a time window of a few seconds to several tens of seconds. Stability in this aspect is the ability of the system to quickly return to a stable operating condition after being exposed to a disturbance such as for example tree falling over an overhead line resulting in the automatic disconnection of that line by its protection system.
4. **Optima Dispatch of Generating Unit (Unit - Commitment):** The problem of a unit commitment involves finding the least-cost,, dispatched of available generation resources to meet the electrical load. Generating resources can include a wide range of types
   (a) Nuclear
   (b) Thermal (using coal, gas, other fossil-fuels or biomass)
   (c) Renewable (including hydro, wind, wave – power and solar)

The key- decision variables that are decided by the computer program are

1. Generation level (in mega watts)
2. Number of generating unit on the letter.

Decisions are binary (0, 1) which that the mathematical problems is not continuous.

In addition, generating plant are subjected to a manner a complex technical constraints inducing.

(1) Minimum stable operating level.
(2) Maximum rate of ramping up or down

(3) Minimum time period the unit is up and or down

Those constraints are amenable to mathematical programming as linear or mixed – integral constraints

TRANSMISSION (OPTIMAL POWER FLOW)

Electricity flows through AC network according to Kirchhoff's laws, transmission lines are subject to thermal limits (simple megawatt limits on flow) as well as voltage and electrical stability constraints the simulator must calculate the flows in the AC network that result from any given combination of unit. Commitment and generator megawatt dispatch, and ensure that AC line flows are within both the thermal limits and the voltage and stability constraints this may include contingencies such as the loss of any one transmission or generation element is so called security – constrained optimal power flow, and if the unit commitment is optimized inside this framework we have a security constrained unit commitment. In optimal power flow (OPF) the generalized scalar objective to the minimized is given by $F(U^o, Xo)$. Where U is a set of the control variables subscript O indicates that the variable refers to the pre-contingency power system. The equality constraint limits are given by the pre and post contingency power flow equations, where K refers to the K^{th} contingency case

$g^k (U^k,X^k) = 0$ for $K = 0$, 1- - - -n

The equipment and operating limits are given by the following inequalities

$$U^k_{\min} \leq U^k \leq U^k_{\max}$$

Represent hard constraints on controls

$$X^k_{\min} \leq U^k \leq X^k_{\max}$$

Represent hard/soft constraints on variables.

$$h^k\left(U_1^k X^k\right) \leq 0 \text{ , 1 - - - - -n}$$

Represents other constraints such as reactive reserve limits the objective function in OPF can take on different forms relating to active or reactive power quantities that we wish to either minimize or maximize. For example we may wish to minimize transmission losses or minimize real power generation costs on a power network.

TRANSMISSION LINE RELIABILITY MODEL

As mentioned earlier, the transmission line is the demonstrates other components such as generating units, transformers, etc. can also be used the reliability data include the failure rate Xs repair rate Us and forced outage rate (FOR) 9. The outage capacity model for a single line with capacity Z.

SIMULATION RESULTS

In this section, the simulation results for estimating the probability of contingency event and system reliability are presented.

PROBABILITY AND BELIEF CONTINGENCY EVENT

Weather status and failure rate of exclusive devices, in this case, transformers, circuit-breakers, etc. is among the known causing line outages. The protective devices can also be considered when operated to protect the system. The initial probabilities are as shown in figure 3.7 upon the receiving of the evidence e_x and posted to the node X, constraint given by equation as

Bel (x) = P(Xle) = are (x) x (x) ……… (1)

Where to (x) and λ (x) represents the distribution of the total supports among the states of X through Eigen values and Eigen vectors.

ASSESSING RISK PROBABILITY

Risks involved are merely events or circumstances that might occur and if they did, how would they affect the operating conditions of the power system. This is quantified by evaluating the maximum load to be constrained, operating costs, etc. once they can be identified, the scales for measuring the probability and impact it is perfectly possible to weight risk in terms of high, medium or low or numerically. Generally, the probability presents the answer to the main question of low likely the uncertainty is to occur (probability). The effect (impact) of the contingency event is another component towards the evaluation of the risk in which the system is involved with during the contingency events such as transmission line outages, generation unit outages, etc. It is therefore important to assess probability with some degree of confidence

SYSTEM RELIABILITY

In this section, the theory behind power system reliability using probability method is presented for clarification of the reliability, the transmission line and generation unit components are used Both enable operational (up) or in outage (down) state. These states have a direct influence upon the power system reliability.

CHARACTERISTIC OF COMPONENT FAILURE

The characteristic of component failure is based on its continuous working time, failure rate function d(t), and mean time between failure (MTBF) (Wang and McDonald, 1994). The mean time before failure is the mean of random variable T, which is another index to evaluate a component's reliability

REPAIR AND AVAILABILITY CHARACTERISTIC OF COMPONENT

The repair process depends on the random factors such as, causes of the failure, failure location, repair facilities, degree of damage etc. therefore, the repair Time To is also a random variable. The mean time to repair (MTTR) is the mean of the component's repair time therefore the relationship between the repair rate M and mean time to repair is given as

$$MTTR\frac{1}{N}---------------(9)$$

The steady state availability (A) is used given as (Wang and McDonald, 1994)

$$A=\frac{N}{\alpha\times u}-------------- \quad (10)$$

Power system probability is to analyze the maximum load into certain operating system. This load system determine voltage node and load network components, generator supply the electrical energy transmission and distribution network and underground cables deliver the electric energy to consumer where all manner electrical load, the electrical load are arranged to ensure that current in each a individual phase are roughly equal. It is the selection of necessary lines and equipment which will deliver the required power and quality of service for the lowest overall average cost for service life. Transformer into all these the generated voltage for sufficient transmission a long distance and decrease the system voltage for local distribution and utilization.

CONCLUSION

Power system probability is to analysis the maximum load into certain operating system this determine voltage node and load network component which generator supply the electrical grid and performing control system parameter estimating the probability of contingency event and reliability are presented.

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