EVALUATION OF RELIABILITY INDICES IN RESTRUCTURED POWER SYSTEMS USING GENETIC ALGORITHM

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Abstract: In the current power systems the reliability evaluation process plays a major role due to system restructuring and addition of renewable power generators. Some new problems occurred in the system reliability management due to deregulation of power system. In this paper generation company and transmission systems are represented with their equivalent multi-state models and their effects on reliability indices are evaluated individually using genetic algorithm. Reliability network equivalent techniques are improved to include the effect of wind speed in the generation systems. The proposed technique is illustrated using Roy Billinton test system and the results are compared with other techniques.

This paper reports the application of Genetic Algorithm on a Roy Billinton test system to calculate the reliability indices. The results are compared with those obtained using the standard optimal power flow approach.

Keywords: Reliability Network equivalent techniques, Genetic Algorithm, Multi-state model, Newton-Raphson method, Reliability management.

NOMENCLATURE

GENCO Generation company

WTG Wind Turbine Generator

EBLP Equivalent bulk load point

EENS Expected energy not supplied

LOLE Loss of load expectation

ATC Available transfer capability

EMGP Equivalent multistate Generation Provider

EMTP Equivalent multistate Transmission provider

MDC Maximum Deliverable capacity

RNET Reliability network equivalent techniques

1. INTRODUCTION:

The application of renewable energy in the electrical power systems is growing rapidly due to the enhanced public concern for adverse environmental impacts due to the conventional fossil energy resources. Conventional fossil fuels such as oil and gas cause environmental problems and are diminishing around the world. Electric utilities are very much interested to utilize the renewable energy resources like wind energy to replace the fossil fuels. Because of the unpredictable nature of the renewable energy resources power output from the renewable generators is different from that of conventional sources. Wind speed multistate models have been developed for the reliability evaluation process to make them suitable for power system applications. The model of a wind farm depends on various factors such as wind speed model, power output model of each wind turbine generator (WTG) and the reliability model of each WTG.

Power system restructuring with high renewable energy penetration resulted in various new problems for reliability evaluation. One of the major problems is the large computational time due to the increased number of renewable generators. In this regard, the reliability network equivalent techniques have been introduced to simplify the calculation.

Power systems are undergoing considerable changes regarding structure, regulations and ownerships. In the restructured power market customers are the centre of attention and restructuring is being realized to maximize the consumer choice, promote the competition and improve the quality of services provided by the electric enterprises. A customer potentially has a wide range of choice regarding power suppliers based on the reliability and price in the deregulated power market. Deregulation is a new force in modern power systems where unbundled generation and transmission facilities can belong to different owners unlike monopoly market where customer has no choice.

The major factor affecting the restructured power systems is not system reliability but individual load point reliability of customers. The quality of service at the customer side is affected by various factors like generation, transmission, distribution and power system operation. For reliability evaluation the effects of these factors on the power systems operation are to be considered individually because of the different nature of their activities. So these factors have been unbundled in the new market environment.

When a wind energy conversion system (WECS) is added to a power system, there are some buses for connection. The location of a WECS causes different effects on the reliability of load points. Reliability network equivalent techniques (RNET) are used to determine the effects of different locations on the load point reliability indices.

2. EVALUATION TECHNIQUES:

There are various techniques which incorporates the WECS models suitably in conventional approaches for reliability assessment of a restructured power system such as analytical methods and Monte Carlo sequential simulation technique. Analytical methods represent the system by using analytical models to calculate the system reliability indices using mathematical solutions. The loss of load expectation (LOLE) and the expected energy not supplied (EENS) are the reliability indices calculated in this paper.

In the new environment, the right of a customer to select its power provider is based on the load point reliability indices where reliability and price becomes centre of attention. After restructuring, a vertically integrated system is represented with generation companies (Genco), transmission companies (Transo), and distribution companies.

These companies provide different services to the customers at various prices and it is difficult to solve the new problems using conventional techniques. The reliability network techniques are developed to meet the challenges in the new environment. These techniques divides a composite power system into equivalent multistate generation providers(EMGP),equivalent multistate transmission providers(EMTP), and equivalent bulk load points(EBLP).Here the effect of generation and transmission are considered separately.

In this paper, the reliability network equivalent techniques (RNET) techniques are improved to include the effect of wind speed in generation systems. Furthermore, a novel reliability network equivalent technique is proposed to determine the effect of generation and transmission system on the reliability of load points separately. The maximum deliverable capacity (MDC) is calculated at each load point in each contingency case using the proposed novel technique. MDCs are used to form a unique multistate model with respect to each and every load point. This model avoids the repeated calculations of EMGP and EMTP for every customer when load and supply levels change. This approach can significantly reduce the computational time and also maintains the accuracy. This technique is applied to the Roy billinton test system to illustrate the benefits of the proposed approach compared to other approaches.

3. MAXIMUM DELIVERABLE CAPACITY:

With the restructuring of electric power industry, the transmission transfer capability of an interconnected power system is becoming an important concern of both system planners and operators which led to the definition of available transfer capability (ATC). ATC is a measure of the transfer capability remaining in the physical transmission network for further commercial activity over and above already committed uses.

In an open-access environment, the MTC for a system state is defined as the maximum power transferred from a source area to a sink area for a given set of system conditions without affecting the other generators and loads in the rest of the system. Therefore, the MTC can be solved as a constrained nonlinear programming problem with an objective function to determine

In this paper, the new concept of MDC is introduced which is similar to the ATC and MTC, to determine the maximum capacity that can be supplied by EMGPs and EMTPs to the respective load points without any network violation takes place.

The objective of the problem is to supply as many loads as possible with their maximum demands. It is a multi-objective function with many aspects such as reduction of power losses, minimizing both fuel cost and also its impacts on the environment and improving the voltage profile, reducing the cost of active power loss and voltage deviation and minimizing reactive power source investment cost etc.

The main objective function is given below

$$\min_{P_G, P_D, Q_G, Q_D} \left\{ \begin{array}{l} \sum_{k=1}^{N_b} \left(f_{1k}(P_{DK}) + f_{2k}(Q_{DK})\right), \\ \sum_{k=1}^{N_b} \left(f_{1k}(P_{GK}) + f_{2k}(Q_{GK})\right) \end{array} \right\}$$

subject to the following constraints

Power flow constraint

$$(P_{GK} + P_{DK}) - P_{LK} - V_k \sum_{\substack{m=1 \\ m \neq k}}^{N_b} V_m (G_{km} \cos\theta_{km} + B_{km} \sin\theta_{km}) = 0$$

$$(Q_{GK} + Q_{DK}) - Q_{LK} - V_k \sum_{\substack{m=1 \\ m \neq k}}^{N_b} V_m (G_{km} \sin\theta_{km} + B_{km} \cos\theta_{km}) = 0$$

There are many methods to solve multi-objective optimization problems, but they require more computational time and some other encounter difficulties in generating the optimal set of solutions. To overcome these difficulties a novel OPF-based technique is proposed.

The general procedure for determining the MDC at each contingency state is given below:

1. Set the appropriate generation for each
2. Genco. Set the loads to their peak
3. Perform OPF
4. Check network constraints. If there has been no go to 5, otherwise go to 6.
5. Increase loads at each load point in small steps and 3.
6. If the loads are already increased during previous to 7, otherwise change the loads to remove remaining in 3.
7. The new load value at each load point is the corresponding MDC for state i.
8. If all the states have been investigated, output probability table for each load point and stop the otherwise go to step 2.

The new load level at each bus, just before the violation, indicates the MDC to that bus.

4. RELIABILITY NETWORK EQUIVALENT OF A GENCO AND TRANSMISSION SYSTEM

1.Reliability network equivalent of a Genco

A Genco can be represented by an EMGP. The characteristics of an EMGP are represented by an available capacity probability table (ACPT).

For an N-unit EMGP with M failed units,the state probability Pi, and its corresponding available generating capacity AGCi for state i can be determined by (9) and (10)

$$\text{Pi} = \prod_{j=M+1}^{N} A_j \times \prod_{j=1}^{M} U_j \quad (9)$$

$$\text{AGCi} = \sum_{j=M+1}^{N} G_j \quad (10)$$

Where A_j, U_j, G_j are the availability, unavailability and available generating capacity of unit j, respectively.

When a wind farm is added to a generation companies with the conventional generating units, the conventional EMGP and the multistate model of the are combined to form new EMGP(EMGPN) as shown in below figure.

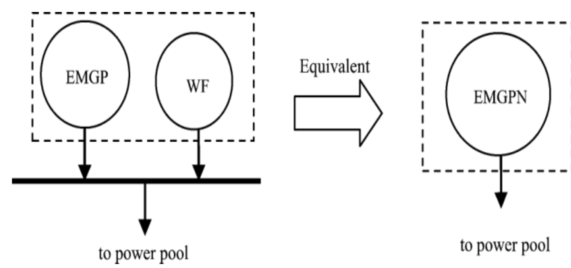
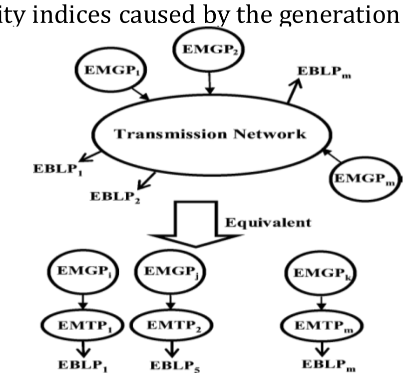


Fig. 1. Modeling new EMGP including wind farm.

The ACPT formed using the calculated Pi and been directly implemented to obtain the portion of reliability indices caused by the generation system.



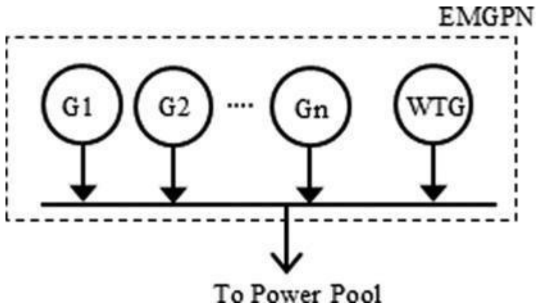


Fig 2. Transmission system and the corresponding EMTPs

The probability of contingency state I in a transmission grid which consists of N transmission lines with M failed lines, is determined using below Eqn.

$$Pi = \prod_{j=1}^{M} U_j \times \prod_{j=M+1}^{N} Aj \qquad (11)$$

Where Aj and Uj are the availability and unavailability of

line j.

5. GENETIC ALGORITHM

Genetic algorithm is nothing but the process of natural evolution obtained from a population of a single model in the genetics. The figure 2 represents the standard procedure of genetic algorithm. They constitute the following five components:

1. The variables characterizing an individual are represented by chromosomes.
2. Initial individual population.
3. An interpreted equation which takes up the operation of the environment is played by a particular evaluation function which rates the individuals with their values of fitness in the environment, i.e., its strength to sustain.
4. The formation of new population produced is determined by the genetic operators from the before one through a process same as the reproduction.
5. Values of different variables like size of population, the probability function of using the operators consisted in genetics, etc. that are used by GA's.

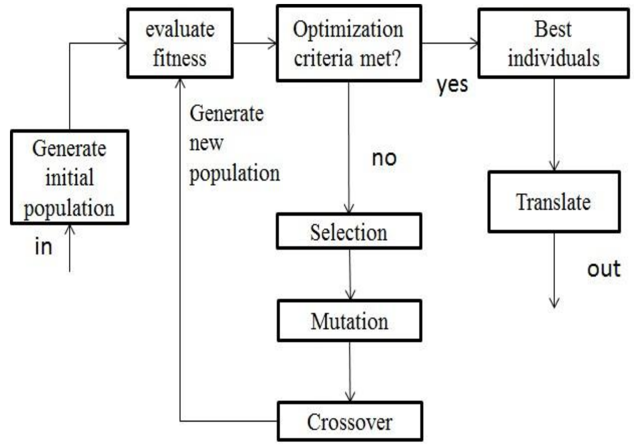


Figure 2: Standard procedure of Genetic Algorithm

A. Representation

The up surged problem that is taken into consideration is used to get the MDC amid two junctions thus increasing the generation at one end while the load at the other one. MDC is the maximum deliverable capacity at the receiving end. As the accuracy of the solution relies on upon the quantity of bits utilized for speaking to what might as well be called the control parameters in the twofold encoding procedure, the control variables are represented using the floating point numbers. This is a fast and convenient scheme for coding which ensures the reduction of possibilities of error. Every candidate chromosome comprises of an array of power generated on the sending end and a set of loads on the receiving end.

B. Initialization

The strings consisting of initial population are selected randomly in the set of the variables that controls the operation. These control variables become self-restricted because of the constraints imposed on them which are used as the intervals.

C. Fitness Evaluation

The optimal solution is searched by the genetic algorithm by incrementing the predefined equation defining the fitness values, and thus an assessment equation has to be provided with a solution which gives a quality measure of the problem. The evaluation function differentiates among the good and the weak results, in the possible and impossible search sets. The value of fitness is very crucial for the operation of the GA, as an individual's chance to get selected is determined by this function which reproduces the lineaments to the next generations. The fitness equation is written in the generic form :

k represents the state variables of the system, i and i the coefficient of penalty and the function of penalty is given by the terms i and i respectively. The load flow functions based on equality constraints are settled using fast decoupled algorithm. A penalty is assigned to the fitness of each chromosome that violates the power flow. The infringements in the constraints are classified in three types: quadratic penalty terms are assigned for voltage violations, square roots of infringements in reactive power, and infringements in the line flows are considered directly. Thus the possibility of selection of the chromosomes which is violated as a parent for later reproduction procedure is less.

D. Reproduction

Individuals participating in consecutive generations are produced in a reproduction process. Depending upon the fitness values of the individual strings, they are duplicated into a mating pool. The probability of providing one / more than one offspring in the next generation is based completely on the value of the fitness of the strings. The mates are selected by the geometrical selection.

E. Mutation

The instantaneous changes in different chromosomes are produced by the Mutation, it is essential to introduce an unreal diversity in the individual's population for avoiding immature meeting to nearby optima. Non- uniform transformation is done in this paper.

F.Crossover

The principle genetic operator that is in charge of worldwide hunt property of GA is the Crossover operator. It focuses on the consolidating of hereditary data acquired from any two unique individuals and shaping another individual. Arithmetic crossover is connected in this paper, characterized by any two corresponding straight blends of the folks.

6. RELIABILITY INDICES

Several reliability indices have been introduced to evaluate system and load point reliability. The loss of load expectation (LOLE) and the expected energy not supplied (EENS) are implemented to illustrate the proposed technique. These indices for a given period of time can be calculated using below equations:

$$LOLE_k = \sum_{j=1}^{N_t} \sum_{i \in LC_j} p_i$$

$$EENS_k = \sum_{j=1}^{N_t} \sum_{i \in LC_j} p_i L_{kij}$$

(h/period)

Where L_{kij} is the load curtailed at bus k for load level j because of contingency I, LC_j is the set of contingency states leading to load curtailment for load level in the study period and Pi is the probability of contingency I at which load curtailment occurs for a certain load level.

The load curtailment Lk at any condition is determined by comparing the load desired value with MDCk using the equation

The GDCPT of each EMGP and the TDCPT of each EMTP are determined only once and can be used for different load levels.

7. SYSTEM RESULTS

The RTS [12] shown in Fig. 4 is utilized to illustrate the proposed approach. A wind farm containing ten WTG units is added to bus 1. To clarify the advantages of proposed approach, a time varying load model for 24 h is used. Wind speed data collected over 14 years in a meteorological station in the Netherlands, was used in this study .

It has been shown that wind speed multistate models with at least six states can provide enough accuracy for reliability calculations. The wind speed model is combined with the reliability model of the WTGs to form a ten- state model for the wind farm..

Loss of load occurs in the states at which MDC is less than the load quantity. The load point LOLEs caused by

EMGP for 24h are shown in fig.3. As expected, load point 6 encounters the highest LOLE because of network configuration and the location of Genco's in the system.

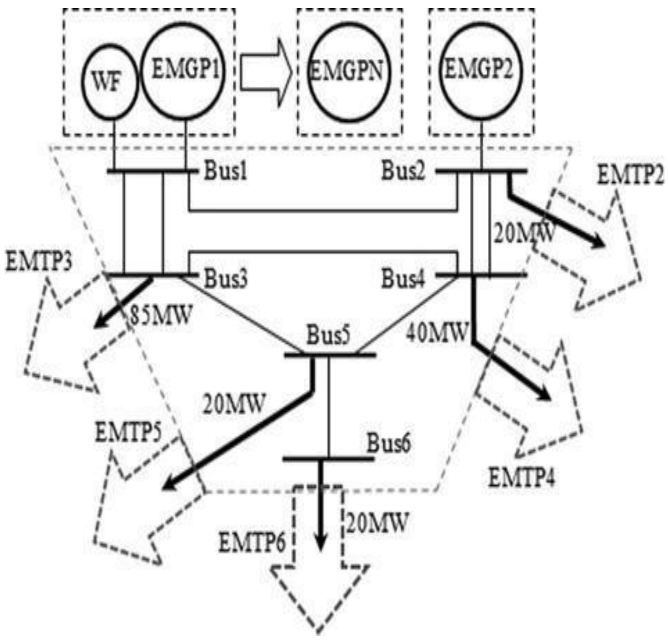


Fig.3 Single line diagram of the RBT

The written program took 78 and 37 s to calculate the reliability indices caused by generation deficiency and transmission failures, respectively. It should be mentioned that the written code is not the most optimized one and using more complex programming skills can reduce the computation time. The total computation time for calculating the reliability indices is almost the same as that for calculating DCPTs. DCPTs are calculated only once and then can be used for any load level; therefore the calculation of daily, monthly and annual reliability indices will take almost the same time using the proposed approach. This approach is very useful especially for real-time calculations because load in a practical system fluctuates with time. Furthermore, the proposed approach can provide additional information about the prospective network such as the maximum load, which can be supplied at each load point.

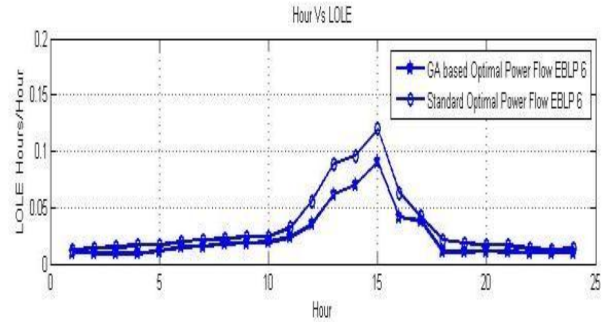


Fig.4 Hourly LOLE of different load points.

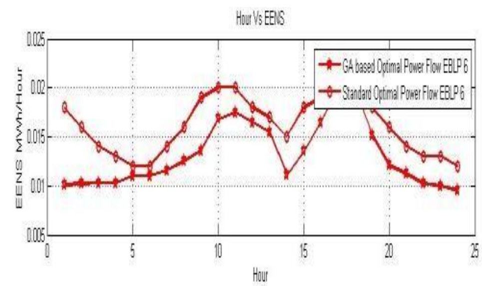


Fig.5 Hourly EENS of different load points for 24h.

The following table shows the reliability indices for different load levels.

Load point (hours)	Lole(h/h)		EENS(MWh/h)	
	Standard opf	Genetic Algorithm	Standard opf	Genetic algorithm
0	0	0	0	0
5	0.02	0.015	0.012	0.011
10	0.0289	0.026	0.020	0.018
15	0.12	0.095	0.017	0.013
20	0.018	0.016	0.0155	0.012

8. CONCLUSION

A novel approach is proposed to determine the maximum deliverable capacity of the transmission network between an equivalent multistate generator and each load point. For a given power system configuration, and a specific load curtailment and generation re-dispatch policy, the DCPT of each load point is unique and is only determined once for different load levels. An equivalent multistate generation provider is also introduced to represent generation system with both wind and conventional generating units. The system studies show that the proposed technique significantly reduces computation burden when both load and supply are subject to change in a power system. The different load shedding and generation adjustment methods can be used in the proposed reliability network equivalent technique. Besides the fast calculation of load point reliability indices, the new approach can be used in transmission system expansion planning. Using the new DCPTs, maximum feasible load at each load point can be easily obtained for the desired reliability level.

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BIOGRAPHIES:

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