EFFECT OF SOLAR AND WIND POWER ON BULK SYSTEM ADEQUACY ASSESSMENT IMPLEMENTING WELL-BEING APPROACH

Bipul Kumar Talukdar

Assistant Professor, Department of Electrical Engineering, GIMT, Guwahati, India

ABSTRACT

Almost all aspects of daily life in modern society depend on the use of electricity. The demand of electricity is increasing by leaps and bounds due to rapid industrialization and population growth. The concern for the environment due to ever-increasing use of fossil fuels and rapid depletion of natural resources have made to the development of environment friendly non-conventional, alternate and renewable energy sources. Production of electrical energy using solar energy falls next to wind energy among all renewable energy sources. The utilization of such energy can significantly reduce the heavy dependence on fossil fuels and also improves the reliability of the system. Due to intermittent nature of renewable energy sources, the reliability assessment of such sources is not similar to that of conventional energy sources. This paper illustrates the effect on system's adequacy due to addition of solar and wind energy sources incorporating the well-being frame-work. It will provide information to the system planners or operators to analyze the actual benefits that can be obtained from proper utilization of solar and wind energy sources and also to decide appropriate selection of energy types, capacity, and mixes for better reliability of the system.

Keyword: *Renewable energy, well-being analysis, adequacy assessment, reliability evaluation, photo-voltaic sources, wind energy, solar energy*

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1. INTRODUCTION

The function of a modern power system is to satisfy the system load at a reasonable cost with a reasonable assurance of continuity. The recognition of 'reasonable assurance' is the basis for a wide range of studies generally designated as reliability assessments. It is a measure of the overall ability of a system to perform its intended function. The concept of power system reliability is extremely broad and covers all aspects of the ability of the system to satisfy the consumer requirements. The term reliability as applied to power systems can be subdivided into the two domains of adequacy and security assessment. [1]

Adequacy of a system is related to the existence of sufficient facilities within the system to satisfy the consumer load demand. This includes the necessary facilities to generate sufficient electrical energy and the associated transmission and distribution required to transfer the energy to the actual customer load points. Therefore, adequacy of a system is concerned with static conditions and does not include system disturbances. [2]

System security is related to the ability of the system to cope with perturbations arising within it. This includes the conditions associated with both local and widespread disturbances and the loss of major generation and transmission facilities. Adequacy, therefore, involves steady-state post outage analysis of power systems, while security involves the analysis of both static and dynamic conditions. [1, 2]

The application of renewable energy in power systems is growing rapidly due to enhanced public concerns for adverse environmental impacts and escalation in energy cost associated with the use of conventional energy sources. [3] The photo-voltaic and wind energy sources are being increasingly recognized as cost-effective generation sources in small isolated power systems primarily supplied by costly diesel fuel. The utilization of these energy sources can significantly reduce the system fuel costs and also have a considerable impact on system reliability. [4]

Reliability assessment of a system requires a wide range of deterministic and probabilistic criteria [1]. Deterministic techniques provide a reliability analysis with information on how a system failure can happen or how system success can be achieved. The most common deterministic criterion dictates that specific credible outages, e.g., single contingency or two critical components will not result in system malfunction. These techniques, which are also often referred to as engineering judgment, do not include an assessment of the actual system reliability as they do not incorporate the probabilistic or stochastic nature of system behavior and component failures. Therefore, these approaches are inconsistent and cannot be used for comparing alternate equipment configurations and performing economic analyses. [2] However, probabilistic methods can respond to the significant factors which affect the reliability of a system. These techniques provide quantitative indices, which can be used to decide if system performance is acceptable or if changes need to be made. However, there is considerable reluctance to using probabilistic techniques in many areas due to the difficulty in interpreting the resulting numerical indices. Although deterministic criteria do not consider the stochastic behavior of system components, they are easier for system planners, designers and operators to understand than a numerical risk index determined using probabilistic techniques. This difficulty can be alleviated by including accepted deterministic considerations in a probabilistic assessment using 'well-being analysis' approach [6], which provides a bridge between the deterministic and the conventional probabilistic method.

2. WELL-BEING FRAMEWORK

Well-being analysis is an approach to power system reliability evaluation which incorporates deterministic criterion in a probabilistic framework and provides information about the system's operating condition as well as risk assessment [7]. It provides a perspective to generation adequacy studies and can also be useful in those situations where conventional probabilistic techniques are not suitable, such as in capacity reserve assessment of a system and in small isolated power system planning. In this approach, the reserve capacity is evaluated using probabilistic techniques and compared to an accepted deterministic criterion, such as load increment, maintenance or the failure of the generating unit, in order to measure the degree of system comfort [6].

System well-being analysis utilizes three indices namely, the probability of healthy state P(H), the probability of marginal state P(M) and the probability of risk state P(R). These three indices indicate the states in which the system can reside. The model [5] for well-being analysis of a system is shown in fig-1.

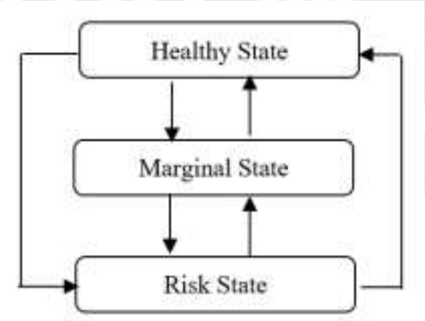

Fig.1: Model for well-being analysis of a system

The probability of health, P(H) states the probability of the system being in the healthy state. In this state, the system has enough reserve margin to meet the predefined deterministic criterion such as the loss of the largest generating unit while all the equipment and the operating constraints are within limits. In other words, the available capacity reserve is equal to or greater than the required reserve so that the demand meets the generation at all conditions [7].

The probability of the system being in the marginal state is defined as the marginal states probability, P(M). The system remains in the marginal state when there is no difficulty but does not have sufficient margin to meet the specified deterministic criterion that can withstand the loss of any single generating unit or branch. If the individual load is either equal to (emergency) or greater than (extreme emergency) the available capacity of the component, the system will enter the state of risk.

The probability of risk, P(R) is also known as the loss of load probability (LOLP). It is the probability of the system being in the risk state. Reserve margin is negative here, i.e.; the load exceeds the available generation.

A system can enter the risk or marginal state from the healthy state due to the loss of certain capacity or due to a sizable increase in load in the system. The probability of healthy, marginal and risk state are collectively defined as the basic well-being indices [6, 7].

3. ALGORITHM FOR DETERMINING THE BASIC WELL- BEING INDICES

Based on the contingency enumeration technique [6], the following algorithm is developed for calculating the well-being indices for a generating system.

Step 1: Read the system's information (number of generating units, capacity of each unit, Forced outage rate (F.O.R) of each unit. Also, read the contingencies (units' up or down states) as well as the system's load.).

Step 2: Calculate the probability and available capacity in contingency state. Also, find out the capacity of the largest unit (CLU) for each state.

Step 3: Calculate the reserve capacity for each contingency state.

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Step 4:   For each contingency state,
          If reserve capacity $\geq$ CLU, assign the probability as healthy state probability.
          If $0 \leq$ reserve capacity < CLU, assign the probability as marginal state probability.
          If reserve capacity < 0, assign the probability as risk state probability.
Step 5:  Evaluate the well-being indices as,
          $P(H) = \Sigma$ (Healthy state probability)
          $P(M) = \Sigma$ (Marginal state probability)
          $P(R) = \Sigma$ (Risk state probability)
Step 6:   Stop.
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4. ADEQUACY ASSESSMENT MODEL

The adequacy assessment of a generating system utilizing Photo-voltaic and/or wind energy sources [8] is done in three steps:

Step1: The necessary atmospheric data is generated for the system site.
Step2: The power delivered by the renewable energy sources is calculated and depends on the weather data provided in the first step.
Step3: The power generated in the second step is combined with the system load data to obtain various adequacy and energy indices.

4.1. Modeling of PV System

The power output of a PV System is a function of the amount of solar intensity at a particular site. Recorded solar radiation data are not available for many locations around the world. Therefore, it is necessary to generate synthetic hourly data for satisfactory evaluation of PV power generation to carry out different studies. The power output from a PV cell can be estimated from its current and voltage (I-V) curves. The curve is the locus of the operating point of the PV cell. The largest rectangle that fits under the I-V curve will touch the curve at the maximum power point

(MPP). The output current increases with increase in solar insolation and the voltage level increase with a decrease in temperature. The I-V curve for a PV module can be constructed by adding the I-V curve of the individual cells contained in it. The rating of a PV module is expressed in peak-watt (Wp) and is equal to the maximum power produced by a module under standard test conditions (STC). [8]

4.2. Modeling of Wind System

Due to the intermittent nature of wind, wind energy conversion systems (WECS) behave quite differently from conventional generating systems and therefore, there are many constraints and assumptions when incorporating wind power in quantitative adequacy assessments of generating and bulk electric systems. The WECS model used in a particular assessment should be compatible with the adequacy assessment technique in use and therefore, potentially there could be a wide range of models [10, 11]. The most important requirement in a WECS model is the ability to provide an accurate portrayal of the intermittency and variability of the WECS power output [11]. The simplest WECS model is an annual multi-state capacity outage probability table (COPT) that can be utilized to create the system COPT used to calculate the loss of load expectation (LOLE) or P(R). Additional factors could include the recognition and incorporation of seasonal COPTs or modified COPTs to include the maintenance scheduling of wind farm. These factors and the resulting WECS models must be compatible with the procedures and protocols established for incorporating conventional generating units in the overall generating capacity adequacy evaluation process [11].

The power produced by a wind turbine generator (WTG) at a particular site is highly dependent on the wind regime at that location. There is a number of ways that wind speed can and has been modeled in power system reliability evaluation [11, 12]. Three of the more common methods involve using the observed wind speeds, using the mean values of the observed wind speeds or using the observed wind speeds to create an autoregressive moving average (ARMA) model.

A WECS model consists of two basic segments: the wind speed model and the WTG model. The nonlinear relationship between the power output of the WTG and the wind speed can be described by the operating parameters of the WTG. Three commonly used parameters are the cut-in (V_{ci}), rated (V_r) and cut-out (V_{co}) wind speeds. WTGs are designed to start generating at the cut- in wind speed, V_{ci}. The electrical power generated per hour can be calculated from the wind speed data using the power curve of the WTG.

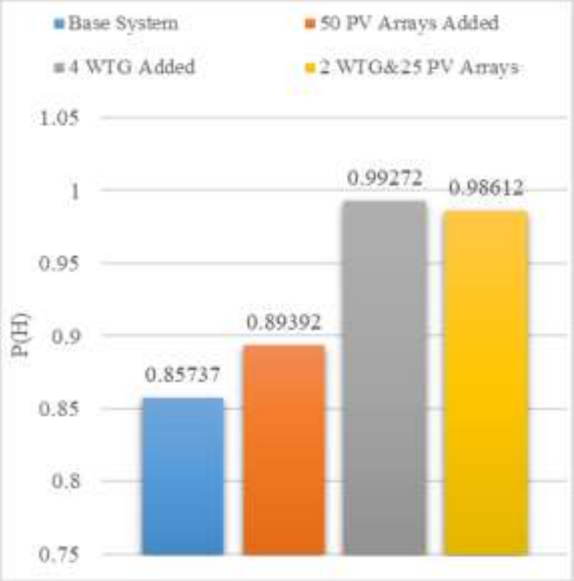
5. CASE STUDY

A base system having two 40kW and one 70 kW diesel generating (DG) units with 5% of unavailability (F.O.R) of each unit is considered for the study. The system peak load is 60 kW.

The effect on system reliability due to the addition of the energy sources to the base system is illustrated by increasing the system capacity by adding a number of WTGs and PV arrays to the base system. Each WTG has a capacity of 10 kW with 4% unavailability. The PV arrays have 810Wp capacity built by assembling 9 groups of 3 series Canrom 30 Wp modules with 4% unavailability.

In the study, the base system capacity is increased by 40 kW in four different ways: 4 WTG added, 50 PV arrays added, and a mix of two WTG and 25 PV arrays added. Fig.2 and Fig.3 show the corresponding P(H) and P(R) of the system due to addition of these energy sources to the base system respectively.

The heath probability of the base system is 0.85737. It is seen that due to the addition of the energy sources, P(H) is increased significantly. On the other hand, the risk



probability, P(R) of the system (0.004875) is decreased due to the addition of the energy sources. It is also seen that improvement of health probability is not to the same degree in the four cases of capacity addition. Improvement of P(H) is more in case of WTG addition than the others and less in case of PV arrays addition. **Fig. 2:** P (H) for different energy sources addition

Fig. 3: P(R) for different energy sources addition

Fig. 4 and fig.5 show the impact of solar and wind energy penetration on the system P(H) and P(R) respectively for a constant system load of 100kW. These figures illustrate that initially, the system reliability improves with the addition of the energy sources, but later the curves representing P(H) and P(R) tend to saturate. Hence, it can be concluded

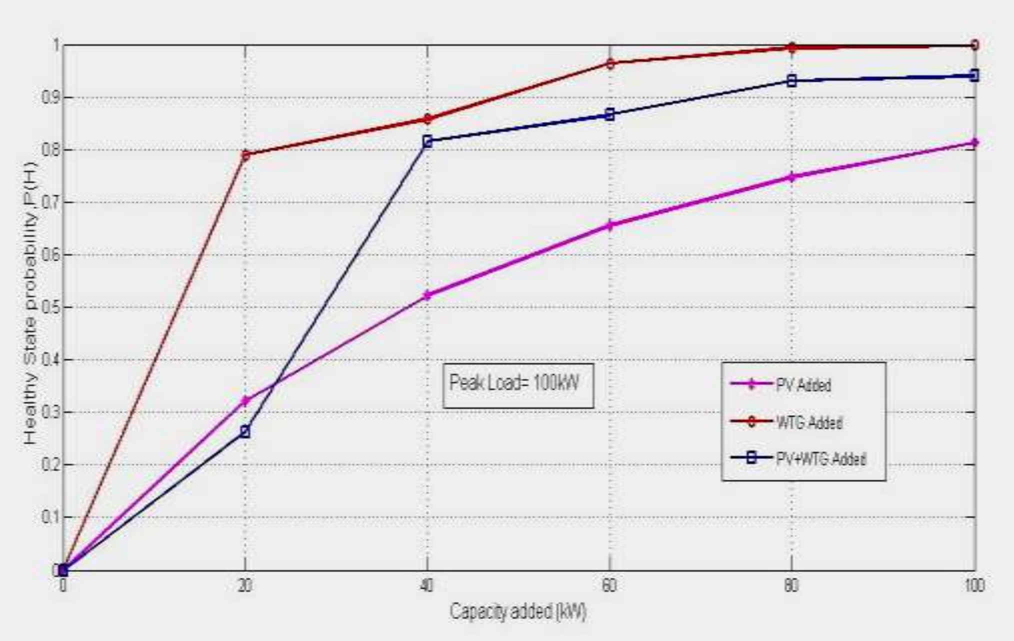


Fig 4: System health probability with increasing penetration

that after a stage, the addition of only solar or wind energy sources to a system will not bring about any substantial improvement in the system reliability. Although an equal amount of capacity is added in each case, the level of improvement is different, depending upon the types of energy source added to the system.

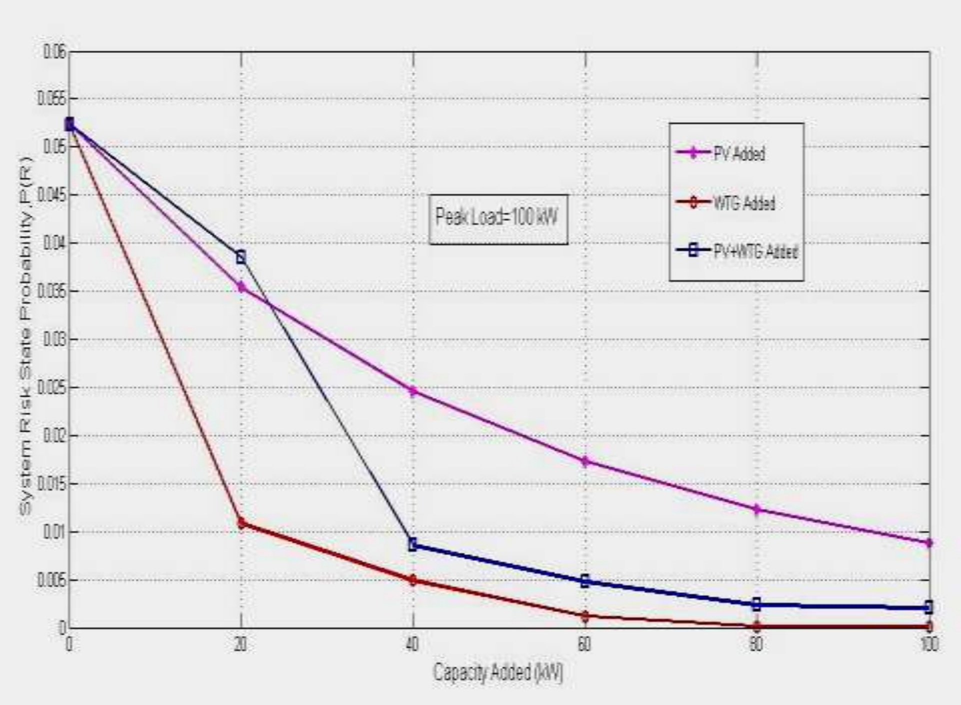


Fig. 5: System risk probability with increasing penetration

Fig.4 and fig. 5 show that the addition of WTGs provides a better reliability as compared to the addition of PVAs of equal capacity. This is due to the fact that PVAs are unable to produce energy during night hours. Moreover, it is also seen that the addition of a mix of PVAs and WTGs in equal capacity ratio results in significant improvement on P(H) and P(R) as compared to the addition of only PV arrays addition.

6. CONCLUSION

The renewable energy sources depend on a large number of random variables, and therefore, the utilization of probabilistic techniques for reliability studies is very necessary. The well-being approach of reliability evaluation provides a bridge between the existing deterministic criteria and the probabilistic techniques. In this paper, contingency enumeration technique is used to determine the three basic well-being indices. The well-being analysis approach can be used to conduct a wide range of system reliability studies in order to analyze the actual benefits that can be obtained. The concepts presented in the paper can be applied to analyze the effects of various factors that influence the utilization of solar and wind energy in electric power systems, and the results can be used as valuable inputs to planning and operation of a system.

System reliability decreases with the increase in load. Changes in load factor or in the shape of the load curve will also affect the system reliability. Maximum benefit can be achieved by injecting a mix of energy sources properly to the system in order to generate a power output profile that closely matches the load profile. Demand side management techniques can also be applied to shape the load curve in order to maximize the utilization of renewable energy available.

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8. BIOGRAPHY

Bipul Kumar Talukdar was born in Assam, India. He received his B.E and M.E Degrees from Assam Engineering College, Guwahati in 2011 and 2014 respectively and presently he is pursuing Ph. D from Guwahati University. He is working as an assistant professor in the Department of Electrical Engineering of Girijananda Chowdhury Institute of Management & Technology(GIMT), Guwahati, India. His area of interest is power system operation, security and reliability.