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A Method for Adequacy Assessment of a Generating System Considering Renewable Energy Sources

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ABSTRACT: Concern for the environment due to ever-increasing use of fossil fuels and rapid depletion of natural resources have made to the development of non-conventional, alternate, new and renewable sources of energy which are also environment friendly. The demand of energy is increasing by leaps and bounds due to rapid industrialization and population growth and hence the conventional sources of energy will not be sufficient to meet up the growing demand. Thus, it has become heir apparent to explore and develop the renewable and non-conventional energy sources. Production of electrical energy using solar energy falls next to wind energy among all renewable energy sources. Due to intermittent nature of such energy sources, the reliability evaluation of renewable energy sources is not similar to that of conventional energy sources. This paper presents a method to evaluate adequacy of a generating system utilizing photo-voltaic and wind energy sources. The well-being frame-work is implemented for the purpose.

KEYWORDS: renewable energy, well-being analysis, adequacy assessment, reliability evaluation, photo-voltaic sources, wind energy

I. INTRODUCTION

The application of renewable energy in electric power system is growing rapidly due to enhanced public awareness of potential environmental impacts of conventional energy sources. Also, the cost of fossil fuels is ever increasing. Photovoltaic and wind energy sources are being increasingly recognized as cost effective generation sources and thereby the use of these energy sources are increasingly promoted to reduce the heavy dependence on fossil fuels [1]. The utilization of these energy sources can significantly reduce the system fuel costs and also have considerable impact on the system reliability.

Due to relatively insignificant contribution of renewable energy sources in large power systems and consequently due to the lack of appropriate techniques, the reliability aspects of utilizing these sources have largely been ignored in the past. Because of the unpredictable nature of renewable resources, power output from renewable power generators is inconsistent and different from conventional units [2, 3]. The intermittent behavior of such sources degrades the reliability of the system. But a relatively high penetration of these energy sources in small isolated power systems can create significant impacts on reliability. In this paper, reliability (adequacy) is evaluated for a generating system utilizing renewable energy sources implementing the well-being framework [4, 5, 6].

II. WELL-BEING FRAMEWORK

System 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. This approach provides a perspective to generation adequacy studies and can also be useful in those situations where conventional probabilistic techniques are not normally accepted, such as in system operating capacity reserve assessment and in small isolated system planning. In this approach, the capacity reserve is evaluated using probabilistic techniques and compared to an accepted deterministic criterion, such as the loss of the largest unit, in order to measure the degree of system comfort [6].

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System well being analysis utilizes three well being indices namely, the probability of health P(H), the probability of margin P(M) and the probability of risk P(R). These three probabilities reflect the three states in which the system can reside. The model [5] for well-being analysis of a system is shown in Fig.1.

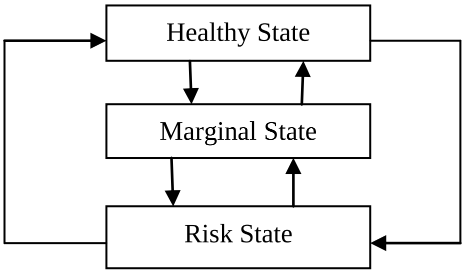

Fig.1 System Well-being Model

The probability of health, P(H) is the probability of the system being in the healthy state. In this state, the system has enough reserve capacity to meet the deterministic criterion such as the loss of the largest generating unit while all the equipments and the operating constraints are within limits. In other words, the available reserve is equal to or greater than the required capacity reserve so that the demand meets the generation at any condition. [7]
The probability of the system being in the marginal state is defined as the probability of margin, P(M). The system operates in the marginal state when it has no difficulty but does not have sufficient margin to meet the specified deterministic criterion, that is 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 at the risk state or marginal state from the healthy state due to the loss of certain operating capacity or due to a sizable increase in the system load. The probability of health, margin and risk are collectively known as the basic well-being indices [6, 7].

III. ALGORITHM FOR DETERMINING THE BASIC WELL- BEING INDICES

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

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Step 1:Read the system's information i.e. number of generating units, capacity, mean time to failure (MTTF) and mean time to repair (MTTR) of each unit. Also, read the contingencies (i.e., units' up or down states) as well as the system's load.
Step 2: Determine the probability and available capacity for each contingency state. Also, determine the capacity of the largest unit (CLU) for each state.
Step 3: Determine reserve capacity for each contingency state as,
        Reserve capacity = Available capacity – System load.
Step 4: For each state,
        a. If reserve capacity ≥ CLU, assign the probability as healthy state probability.
        b. If 0 ≤ reserve capacity < CLU, assign the probability as marginal state probability.
        c. If reserve capacity < 0, assign the probability as risk state probability.
Step 5: Calculate 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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IV. ADEQUACY ASSESSMENT MODEL

The adequacy assessment of a generating system utilizing Photo-voltaic and/or wind energy sources [8, 9] 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.

The model [1] for adequacy assessment of a small generating system consisting of photo-voltaic (PV), wind turbine generator (WTG) and diesel generator (DG) is shown in Fig.2

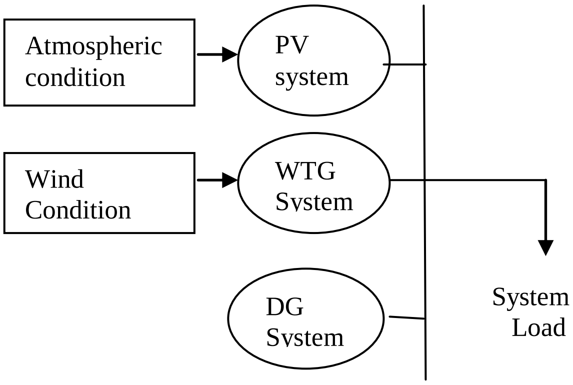

Fig.2. Model for adequacy assessment

A. 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 schematic diagram of PV system is shown in Fig.3.

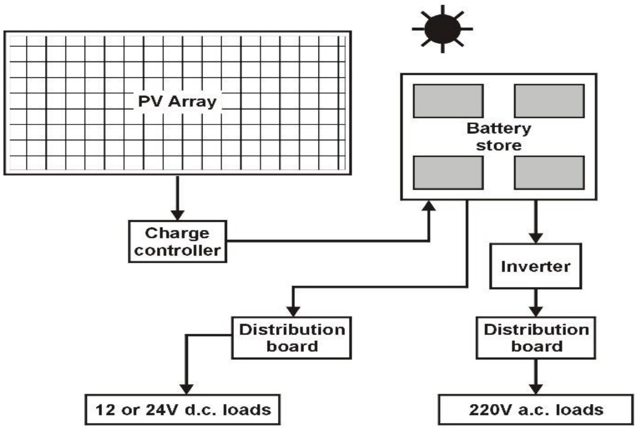

Fig.3. Schematic diagram of PV System

The power output from a PV cell can be estimated from its current and voltage (I-V) curves, as shown in Fig.4. 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 increases with a decrease in temperature [1]. The I-V curve for a PV module can be constructed by adding the I-V curve of the individual cells contained in it.

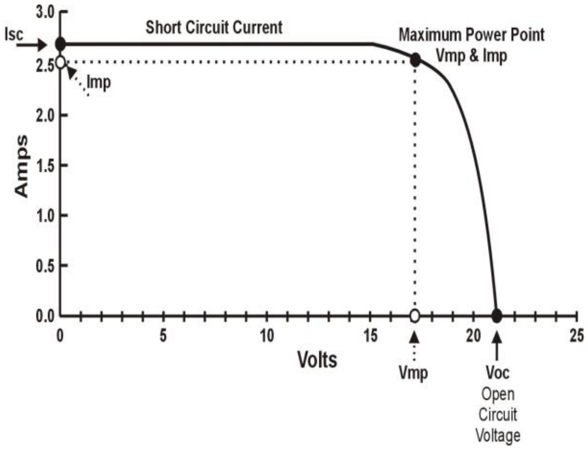

Fig.4. I-V Characteristics of PV Cell

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). STC corresponds to a radiation level of 1 kW/m^2 and a cell temperature of 25˚C. The manufacturers provide the characteristic of PV module under STC by specifying I_{SC} (short-circuit current in A), V_{OC} (open-circuit voltage in V), I_{MPP} (current at maximum power point in A), V_{MPP} (voltage at maximum power point in V), and N_{OT} (nominal operating temperature of cell in ˚C).

The current–voltage characteristic of a PV cell can be determined for a given radiation level *s* and ambient temperature T_A using the following relations [9,10]:

$$T_C = T_A + s\,(N_{OT} - 20)\,/\,0.8 \tag{1}$$

$$I = s\,[I_{SC} + K_I\,(T_C - 25)] \tag{2}$$

$$V = V_{OC} - K_V\,T_C \tag{3}$$

where T_C represents cell temperature in ˚C, I stands for PV module short-circuit current in A, K_I signifies short-circuit current temperature coefficient in A/˚C, V indicates open-circuit voltage in V, and K_V is open-circuit voltage temperature coefficient in V/◦C. The power output from a PVA, containing total N modules, can be directly calculated as,

$$f^{PV}(s) = NFFVI \tag{4}$$

where $f^{PV}(s)$ is a function of solar radiation level s for calculating power output from a PVA and fill factor (FF) depends on the material of PV module, and is given by the following relation:

$$FF = (V_{MPP}\,I_{MPP})/\,V_{OC}\,I_{SC} \tag{5}$$

B. Modeling of Wind System

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

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 actual observed wind speeds, using the mean values of the observed wind speeds or using the observed wind speeds to create an auto regressive moving average (ARMA) model. These three methods can be briefly described as follows.

A. ***Observed Wind Speeds:*** This method uses an observed hourly wind speed (Ob) data set repetitively in the reliability evaluation sequential simulation process.

B. ***Mean Observed Wind Speeds:*** The mean of the observed (Mob) wind speed for each hour is calculated based on different annual wind speed data sets. The hourly mean wind speed data set is then used repetitively in the sequential simulation process.

C. ***ARMA Model:*** This method uses the ARMA model [13] to predict wind speeds in the reliability evaluation process and is designated as the ARMA approach. An ARMA model with ϕ_i autoregressive terms and Θ_j moving average terms is denoted as ARMA (ϕ_i, Θ_j).

$$y_t = \phi_1\, \Theta_{t-1} + \phi_2\, \Theta_{t-2} + \ldots + \phi_n\, \Theta_{t-n} + \alpha_t - \Theta_1\, \alpha_{t-1} - \Theta_2\, \alpha_{t-2} - \ldots - \Theta_n\, \alpha_{t-n} \qquad (6)$$

In the simulation process, y_t is produced using the above equations. The simulated wind speed at hour t, designated as SW_t , can be calculated by using Equation (7)

$$SW_t = \mu_t + \sigma_t * y_t \qquad (7)$$

where μ_t is the mean observed wind speed at hour and σ_t is the standard deviation of the observed wind speed at hour.

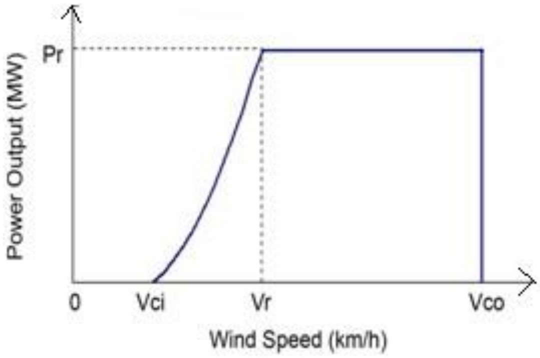

Fig.5. Wind turbine generator power curve

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. The nonlinear relationship between the power output and the wind speed is shown in Fig.5.

WTG are designed to start generating at the cut- in wind speed, V_{ci}. Figure 5 shows that the power output increases non-linearly as the wind speed increases from V_{ci} to the rated wind speed V_r. The rated power, P_r, is produced when the wind speed varies from Vr to the cut out wind speed, V_{co}, at which the WTG will be shut down for safety reasons. The electrical power generated hourly can be calculated from the wind speed data using the power curve of the WTG.

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V. 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 assumed to be 60 kW.

To illustrate the effect on reliability due to addition of renewable energy sources to the system, the system capacity is increased by adding some 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, a mix of two WTG and 25 PV arrays added and finally one DG with capacity 40 kW and unavailability 5% is added. Fig.6 and Fig.7 show the corresponding P(H) and P(R) of the system due to addition of these energy sources to the base system respectively.

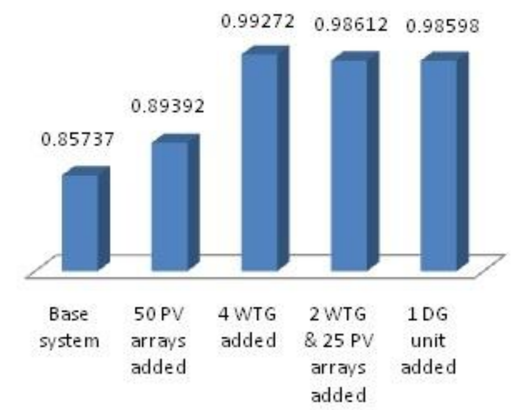

Fig.6. P(H) for different energy sources addition

Fig.7. P(R) for different energy sources addition

The heath probability of the base system is 0.85737 which is increased significantly due to addition of renewable energy sources. On the other hand, the risk probability of the system (0.004875) is decreased due to the addition of renewable 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.8 and Fig.9 show the variation of P(H) and P(R) due to load growth for the four cases of capacity addition respectively. 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 in utilizing renewable energy 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.

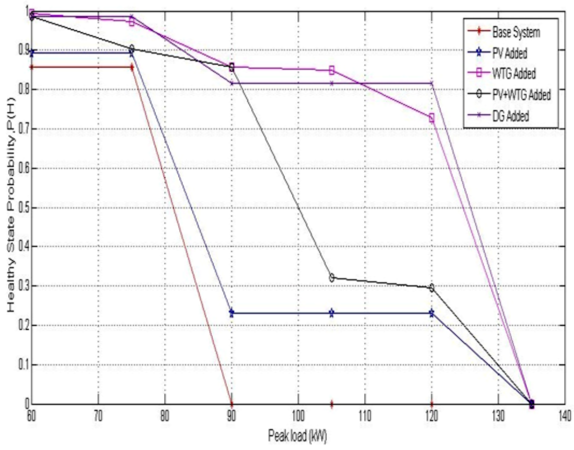

Fig.8. System Healthy state Probability with load

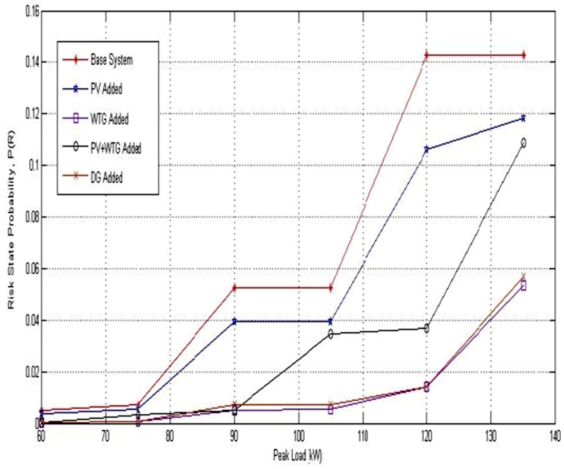

Fig.9. System Risk Probability with load Growth

The reliability of the system increases with the increase in system available capacity. Fig.10 and Fig.11 show the impact of renewable energy penetration on the system P(H) and P(R) respectively assuming a constant system load of 100kW. These figures illustrate that initially the system reliability improves with addition of renewable energy sources, but later the curves representing P(H) and P(R) tend to saturate. Hence, it can be concluded that after a stage, the addition of only renewable 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.

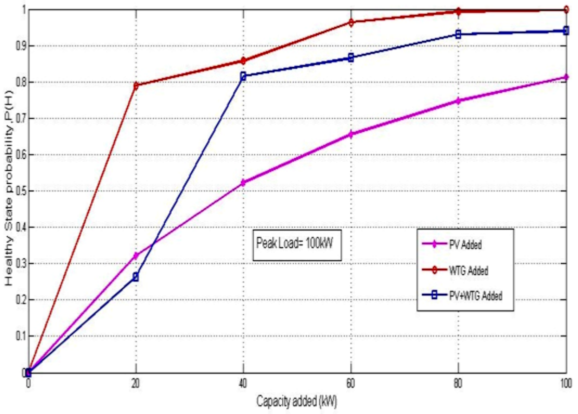

Fig.10. System health probability with increasing penetration

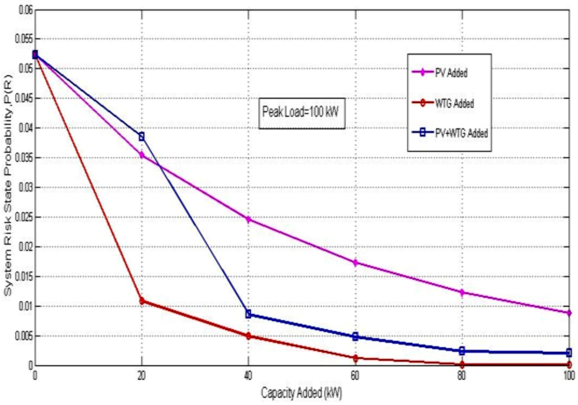

Fig.11. System risk probability with increasing penetration

In Fig.10 and Fig.11, it is seen 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 from Fig.10 and Fig.11 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.

VI. CONCLUSION

In recent years, due to heavy dependence on fossil fuels, the harmful effects of global warming are more and more visible day by day. Also, the cost of fossil fuels is ever increasing. Therefore, the need of developing clean and environment-friendly renewable and non-conventional energy resources is being increasingly realized. Though the renewable energy sources are less reliable compared to the conventional energy sources, proper utilization of such sources can improve the reliability of a system significantly.

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 renewable energy in electric power systems and the results can be used as valuable inputs to planning and operation of a system.

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