Asian Journal of Water, Environment and Pollution, Vol. 16, No. 2 (2019), pp. 15–19.
DOI 10.3233/AJW190014

Reliability Assessment of Renewable (Hydro/Wind/Solar) Energy Systems at Planning Level

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Received January 25, 2019; revised and accepted March 1, 2019

Abstract: Renewable energy systems particularly consisting of hydropower, wind and solar have became an integral part of power industry owing to their benefits over conventional resources. These resources are not only environmental friendly but also lead to more sustainable progress in developing nations especially South Asian countries. In this paper, a reliability criterion has been developed and explained to decide the best configuration for renewable energy systems (consisting of hydropower/wind/solar etc.) during the planning stage. Two different configurations of renewable energy systems have been analyzed for maximum reliability. Logic diagram approach has been used to represent the systems under consideration. Reliability assessment of these renewable energy systems have been carried out to find out the most suitable arrangement of comprising stages. The aim is to develop a most robust system of renewable resources (hydro/solar and wind) to supply the power to the consumer end. The approach is easy to implement and leads to development of a more practical and economically beneficial renewable energy system in developing Asian countries.

Key words: Renewable energy systems, reliability, logic diagram approach, South Asian countries, planning.

Introduction

Reliability is most important aspect of any system. It tells about the system desirability for its intended functions. Thus, reliability can act as one of the deciding tools for the future planning and operation assessment of system under consideration. Electric power has become an utmost important aspect of progress and concern in developing countries. The conventional methods of power generation leads not only to environment deterioration but also fails to promise sustainable growth. So renewable resources like hydro, solar and wind has come up as promising alternatives to these conventional resources. But implementation of these resources needs proper planning and management of available renewable resources. In power system, reliability study covers the assessments of outages and availability. Reliability assessment of these resources at planning level fulfills the above discussed need of renewable energy systems.

It is an established fact that growing power demands have led to great modifications in power network designs. Also, inclusion of new devices such as protection devices etc., at different levels of power systems makes it necessary to assess the well being of overall system to decide the validation of changes made. However, reliability assessment provides an opportunity to study the interruptions and outages as an effect of new changes made in the power industry in the form of renewable energy resources (hydro/solar/wind), smart grids, FACTS devices etc.

A base to identify the effect of uncertainty of components such as unscheduled generator outages, power system interruptions etc. has been provided in

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a study by Schilling et al. (1989). Thereafter, several methods and techniques have been proposed by researchers for the evaluation of reliability of renewable electric power systems. Many reliability methods and their applications as given by many authors (Li et al., 2013; He et al., 2010, Kleyner and Sandborn, 2008; Georgilakis and Katsigiannis, 2009; Green et al., 2011; Li et al., 2004; Véliz et al., 2010; Xu and Mitra, 2011; Kadhem et al., 2017; Billinton and Adzanu, 1996) have been developed over the time for renewable and conventional power systems. Researchers have also shown their interest in cost evaluation of reliability. Moreover, various optimization techniques have been developed for reliability assessment (Vallee et al., 2008, Zou et al., 2014; Paleti et al., 2015; Billinton and Zhang, 2001; Ghajar and Billinton, 2006; Hamdan et al., 2012; Ropke, 2013). Due to renewable energy unbeatable advantages, its importance is increasing day by day in power industry. Inspite of being a promising alternative to conventional resources, renewable energy resources still have number of issues to be dealt with (Mahesh and Sandhu, 2015).

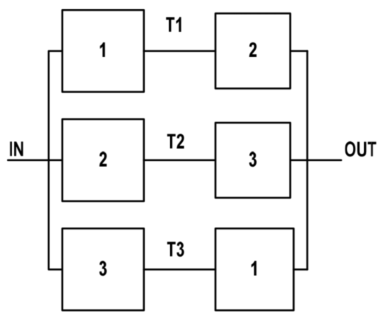
The literature supporting research in reliability assessment of electrical power system incorporating renewable energy resources (hydro/solar and wind) is continuously developing. From study it is evident that reliability is one of the most important aspects to be considered for proper, efficient and economical working of renewable systems. It has huge number of applications in deciding the potential geographical area, economical worth and unit size. Reliability evaluation at various stages of development completes the planning and operation process of renewable energy systems. Analytical, Monte Carlo, hybrid and other methods as in case of conventional system reliability have been implemented to evaluate renewable systems reliability as well (Aggarwal, 2012). Unlike conventional energy system hierarchical levels are not well defined in renewable energy systems and hence are not considered. Transmission level and distribution level are treated as one unit and thus, renewable power system is assumed to have two levels i.e. generation and load.

From literature survey it is found that for reliability assessment of renewable (hydro/solar/wind) power systems, many methods have been developed and evolved. Moreover, reliability has been applied in different parts of renewable power system involving various types of system configurations. But no work is done, utilizing reliability as designing tool during planning stage. This paper concentrates on developing the logic diagram approach to estimate the reliability of a system for its different configuration, in planning stage itself. Reliability assessment at planning stage itself is very fruitful as it saves lot of project failures and hence the cost related to it. Moreover the reliability assessment is quite essential at planning stage only for developing countries mostly in South Asia as economics related to any project turns the equations.

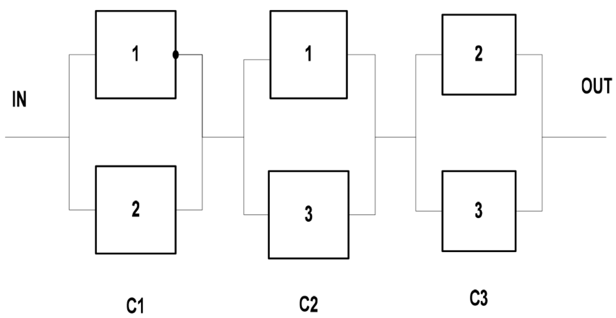
Paper is organized in five parts. First section provides the introductory part. The next section gives brief description of logic diagram approach in reliability assessment of system. The third section includes the description and assessment of renewable system under consideration. The fourth section discusses the outcomes from developed criterion. Fifth section concludes the paper.

Logic Diagram Approach

A simple series-parallel or parallel-series diagram can be considered as logic diagram, which can be easily evaluated for its reliability by the use of the basic laws of probability theory (Balagurusamy, 2012). Logically any energy system can be represented either as TSLD (tie set logic diagram) or CSLD (cut set logic diagram) as shown in Figure 1. In TSLD, some minimum numbers of units need to be good for the overall system to be a success. In CSLD, failure of certain number of units leads to system failure.



(a) Tie-set logic diagram (TSLD)



(b) Cut set logic diagram (CSLD)

Figure 1: Types of logic diagrams.

For standalone renewable systems, all components including wind turbine, solar panels, converter, gear box etc. can be arranged to form a logic diagram. These logic diagrams can thus further be evaluated for assessing the reliability of overall system before its actual commencement. This not only helps in knowing the requirement of improvement in reliability of system but also helps in knowing the individual component having maximum effect on system reliability.

Figure 2 shows the steps involved in logic diagram approach. Any system can be converted to its logic diagram with proper arrangement of its constituent units.

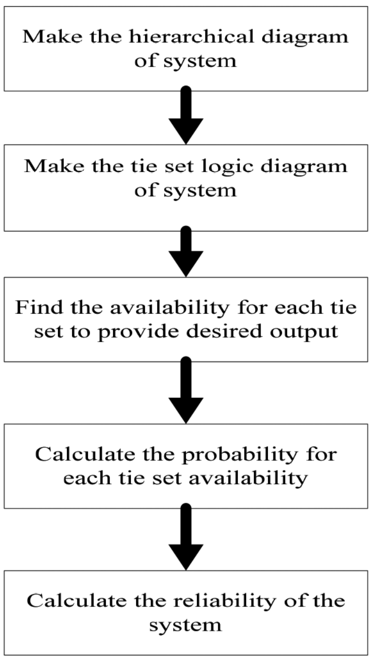


Figure 2: Flow chart for logic diagram based reliability assessment.

Reliability during Planning of Renewable Energy (Hydro/Wind/Solar) System

Proper evaluation of renewable system at planning stage plays a crucial part in successful future operation of system. Different configurations of renewable energy systems comprising different resources can be evaluated and assessed for reliability using logic diagram approach and thus best configuration could be chosen in order to lower the risk of outages for customers. Here, two different configurations have been taken to show the effect of arrangement of components at planning stage on overall reliability.

Let's consider a standalone system with two generators supplying four groups of customers as shown in Figure 3. Here generator unit G is composed

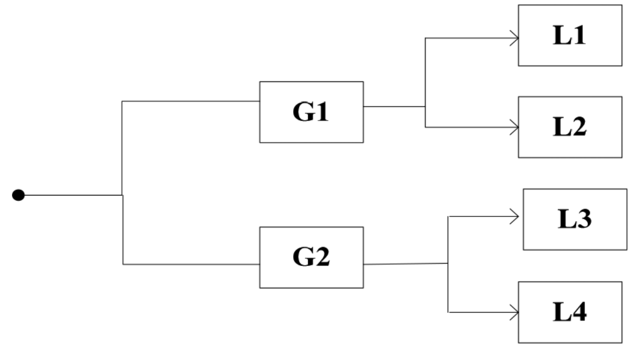


Figure 3: Generator-load configuration of standalone system.

of renewable source generator with controller and load L is composed of battery bank, inverter and load itself.

If the reliability of each load is 0.9 and generator set is 0.8, reliability of overall system can be given as

$$R_{S_1} = \sum_{x_1=k_1}^{2} \binom{2}{x_1} p_1^{x_1}(1-p_1)^{2-x_1} \sum_{x_2=k_2}^{2x_1} \binom{2x_1}{x_2} p_2^{x_2}(1-p_2)^{2x_1-x_2} \quad (1)$$

where k_2 is the number of load units and p_1 and p_2 are reliability of generator G1 and G2.

The probability of at least two load units being supplied is

$$R_{S_1} = \binom{2}{1} p_1(1-p_1) \quad (2)$$

$$\sum_{x_2=2}^{2} \binom{2}{x_2} p_2^{x_2}(1-p_2)^{2-x_2} + p_1^2 \sum_{x_2=2}^{4} \binom{4}{x_2} p_2^{x_2}(1-p_2)^{4-x_2} \quad (3)$$

For given values of p_1 and p_2

$$R_{S_1} = 0.8968$$

In the configuration shown in Figure 3 when a generator set fails, the two loads connected to that set are not supplied irrespective of their status. The reliability of above system can be increased if configuration has been changed as shown in Figure 4. The new reliability of overall system for the new configurations and same reliability of generators and loads is given as:

$$R_{S_2} = \left[\sum_{x_1=1}^{2} \binom{2}{x_1} p_1^{x_1}(1-p_1)^{2-x_1}\right] \times \left[\sum_{x_2=2}^{4} \binom{4}{x_2} p_2^{x_2}(1-p_2)^{4-x_2}\right] \quad (4)$$

$$R_{S_2} = 0.9564$$

Thus, reliability has been increased on changing the configuration.

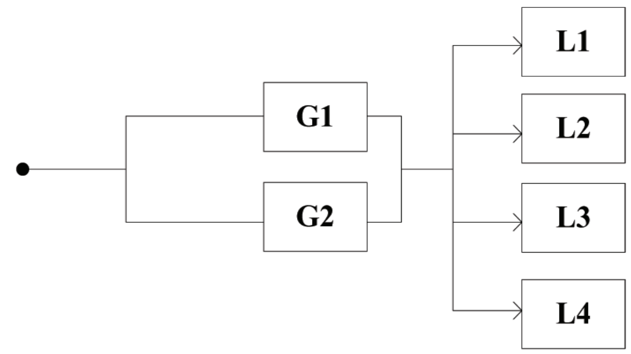


Figure 4: New generator-load configuration of standalone system.

Following cases are taken into account to observe the response of every component's reliability or unreliability of complete system:

Case 1: If the reliability of generators is reduced from 0.8 to 0.7 and reliability of loads is kept same i.e. 0.9 the overall system reliabilities for both the configurations are

$$R_{S_1} = 0.8423$$

$$R_{S_2} = 0.9234$$

Case 2: If the reliability of loads is reduced from 0.9 to 0.8, and reliability of generators is kept same i.e. 0.8, the overall system reliabilities for both the configurations are

$$R_{S_1} = 0.8211$$

$$R_{S_2} = 0.9011$$

Case 3: If the reliability of loads is increased from 0.9 to 1, and reliability of generators is kept same i.e. 0.8, the overall system reliabilities for both the configurations are

$$R_{S_1} = 0.9123$$

$$R_{S_2} = 0.9669$$

Case 4: If the reliability of generators is increased from 0.8 to 0.9, and reliability of loads is kept same i.e. 0.9, the overall system reliabilities for both the configurations are

$$R_{S_1} = 0.9012$$

$$R_{S_2} = 0.9681$$

Outcomes

The overall reliability of the system has increased reasonably when configuration is changed from configuration 1 to configuration 2, as shown in Figure 5.

Similarly the effect of change in reliability of individual components (i.e. generators and loads) for different discussed cases is shown in Figure 6. The change in system reliability from its original value for different cases can be easily observable. Cases 3 and 4 are more favourable as they are showing increased reliability of overall system.

It should be brought to notice that the increase in reliability cannot be achieved without increase in the system overall cost. The rating of generators has to be doubled for configuration 2, which further leads to increased system cost. So, it is recommended that different configurations should be evaluated for cost also. Thus, best configuration on the basis of optimization between arrangement of components and their cost should be selected.

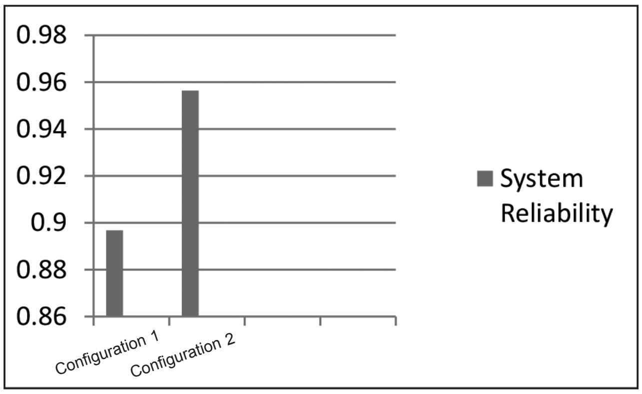


Figure 5: Reliability of different configuration.

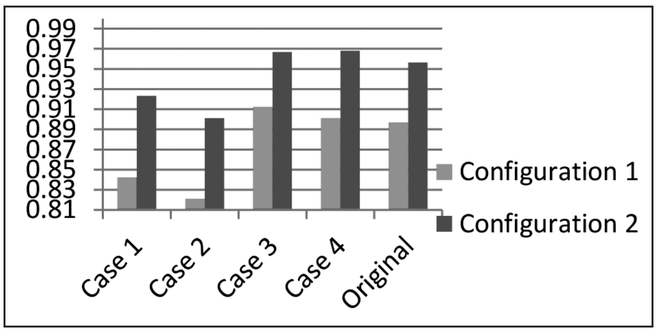


Figure 6: Reliability of different configuration for different cases.

Conclusion

Renewables like hydro, solar and wind systems are gaining consideration due to their inevitable advantages to environment. Much work has been done to extract power from available hydro, solar and wind energy resources and to increase their efficiency. In this paper, work has been presented to assess the reliability of different configurations of standalone renewable system like hydro power systems, wind energy systems and solar energy systems using logic diagram approach. From the work carried out, it is evident that the proposed methods will be able to make the renewable energy systems more reliable if system is assessed at planning level itself. Further, it will be of great help to make the system more efficient and economic which is again a huge benefit for developing countries.

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