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Reliability Assessment of Power System Considering the Impact of Renewable Energy Sources Integration Into Grid With Advanced Intelligent Strategies

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ABSTRACT Power industry is incidenting a change from the present electric grid to a more secure, reliable, capable and advanced smart grid. Renewable energy sources such as wind and solar energy systems will be incorporated and potentially in bid scale in order to obtain these aims. Many possible applications of renewable energy sources have been inspected. In this article, reliability enhancement of power system considering the impact of wind and solar energy sources integration into grid with advanced intelligent strategies is focused. Further, different models are utilized to obtain the proposed renewable energy sources operation. Further, a reliability assessment framework is discussed to examine the reliability impact of renewable energy sources integration into the grid. A comprehensive case study and risk analysis has been performed based on the different risk indexes to show the usefulness of the proposed strategies and assessment framework, and to give precious insight on the reliability impact resulting from the wind and solar energy resources integration into the grid. The main advantages of renewable energy sources integration into grid with intelligent techniques are presented here along with the reliability evaluation. The results of the study reveals that the integration of the solar and wind energy systems into the grid enhances overall the reliability of the entire power system

INDEX TERMS Power system, wind energy system, solar energy system, alternative model-creating technique, alpha model technique, fuzzy fault tree analysis, model predictive control, fuzzy logic control, reliability, grid.

I. INTRODUCTION

With the increased penetration of renewable energy resources like solar and wind energy systems into the existing power system and their increased flexibility in smart grid operation, the power players can make better decisions as for as the improvement in reliability of the power systems as a whole is concerned by incorporating various renewable energy sources into the existing power grid. In addition the demand of electrical energy is increasing on daily basis, so there is a need for a reliable source of energy that can satisfy the future energy scenario, among one of the promising energy source solar-wind hybrid energy system is one such source. Therefore, the reliability enhancement of power system considering the impact of wind and solar energy sources integration into existing grid with advanced intelligent strategies is focused in this article. The rapid growth in the renewable energy sector makes the solar and wind generation structure extra complex and the rate of their failure is increasing consequently. However, the destructive operating conditions and variable load are responsible for the high failure rates [1]. In the solar photovoltaic system Photovoltaic (PV) module and its accessories are the main components whereas gearbox is the key component in the wind energy system and it is used to transmit torque and control the speed. The faults in PV module are because of faults in diode, regulation problem;

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short circuits etc and the faults in wind energy conversion system are mainly because of gearbox failures, long term operation of variable speed loads, unbalance of the shaft, gear damage, broken shaft, etc. The wind generator rotor is the main component of wind based energy network but the rotors of the wind turbine are likely to disturb due to the water in blades, fatigue harm to the blade and unequal icing on the surface of the blade.

In [1] a complete and detailed analysis on reliability, availability and maintainability for all sub-components of the solar photovoltaic systems with grid-tied mode that holds lower value of reliability, taking the failure facts and interval of repairing is presented. Further the work also determines the probability density function to find the fault rate of every sub-component of the solar photovoltaic based system. Moreover, a fuzzy fault tree based technique for evaluating the reliability of the wind based energy system is presented [2]. An optimal sizing methodology for wind-solar-battery hybrid power system and to precise and sensible optimal sizing has been discussed with taking into account that the system is operating in grid linked mode and standalone mode [3]. Further, improvement in reliability of the whole power system network introduced, but, recently solar-wind energy system is beginning to present good reliability in comparison with diesel generators [4]. by the usage of energy storage devices in the distribution networks with the renewable energy sources. Operation technique for energy storage devices which can improve the reliability of the system with renewable energy connection is presented. The stochastic method for reliability analysis and best sizing of hybrid energy system with renewable resources and the energy storage systems have been discussed [5]. Uncertainties in solar and wind power, and the load are modelled stochastically using the autoregressive moving average method. A probabilistic methodology based on analytical technique to evaluate the reliability of the system for distribution systems having non-dispatchable and dispatchable DG units based on energy system is presented in [6]. For a single microgrid the real-time energy organisation system that has an energy storage system, renewable generation system, and the load is discussed in [7]. In [8], the outcomes of the time based resolution of solar based generation with consideration of complete distribution of generators outages are discussed. The optimal operation of the interconnected systems of the multimicrogrids is presented in [9]. Whereas, solar and wind power generation, and power demand with the clusters forms have been presented [10], which could internment the time reliant attributes and keep the associations between the data sets, examines to what degree the output power of the wind energy system can be modelled with the discrete Hidden Markov Models [11]. The reliability analysis of distribution systems set in with renewable distributed generation resources are discussed giving stress on indecisions and optimal repair plans [12]. Further, it is necessary for investigators to get the exact information of the events after the improving the risk factor of the components[13], therefore, different techniques have been used to know the exact effect of the failure to the system [14], [15]. Some methods are being used to know the IT system risk in the premises [16] and investigates the susceptibility of the system with respect to thoughtful disturbances [17], [18]. A combined model has to be built to know the exact impact of renewable energy sources integration to the grid on reliability [19], and different types of analytical reliability models have been used for assessment [20].

The uncertainties that are related with the output power from renewable energy resources, stochastic prediction errors, load demand and random fault actions have been taken care of in the repair optimization preparation for assessment of the reliability. The different models are utilized to obtain the desired renewable energy sources operation. Additionally, a reliability assessment framework has been discussed to observe the reliability impact of renewable energy sources integration into the grid. But the actual data is inadequate; hence the proposed method is used with advanced technique. The input of the wind and solar energy sources varies because of the changes in the solar radiation and wind speed. Earlier techniques have not provided exact results because of the inadequate data, lower process and computational burden. Hence, there is a need of proper balancing the fluctuations and to obtain the advanced controller to maintain a good output of the inverter. This problem can be resolved by using an advanced control system using the fuzzy logic control and model predictive control schemes.

Therefore, in this article, an advanced technique for grid-connected solar-wind energy system risk assessment with inexact and scarce information have been given to conquer the practical reliability investigation problem. This article proposes the three different techniques i.e. alternative model-creating technique (AMCT), two parameters based alpha model technique (TPBAMT) and proposed fuzzy fault tree based technique (PFFTBT) with fuzzy logic based inverter control and model predictive based boost converter control for reliability evaluation of power system considering the impact of wind-solar energy systems integration into grid.

These techniques have been applied to know the various reliability indices and failure likelihood of the top occurrence with changing the load.

The obtained results are compared with different old techniques. The Renewable Energy Probabilistic Resource Adequacy (REPRA) tool is developed at NREL to know the reliability condition. It has lengthy procedure and requires more time to know the exact value. Whereas, Bulk power system reliability assessment structure gives the improvement in the reliability indices as presented in [4] with utilization of energy storage device hence involves higher cost and more losses.

This article is arranged as follows: Section II presents the renewable energy sources operation in the distribution networks. Section III represents the hybrid energy system reliability analysis framework. Section IV describes the intelligent controller based grid connected hybrid energy system.

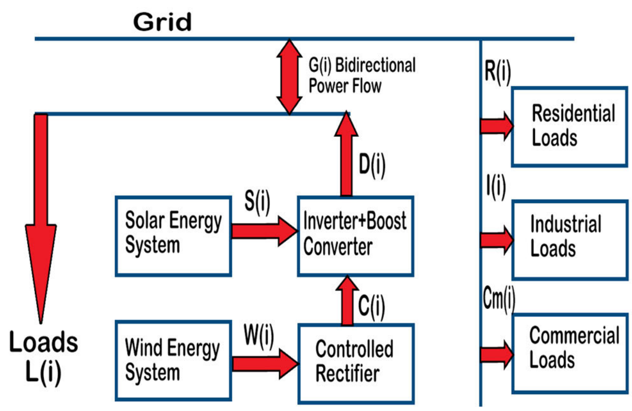

FIGURE 1. Distribution system integrated with renewable energy sources.

Case studies are discussed in Section V. The Conclusions portion is given in Section VI.

II. RENEWABLE ENERGY SOURCES OPERATION IN DISTRIBUTED SYSTEM

The small scale customers situated in a distributed system generally do not openly take part in the electricity market to buy power they require. As a substitute, a load collector is a unit which contributes in power market, and takes the power for its consumers and provides the power to them. The load collector's aim is to provide its customers constantly at the same time as reducing cost. With the connection of renewable energy resources like wind and solar energy systems, a load collector has more suppleness in organizing energy deal and supply.

The system topology with renewable energy resources and power converters is simplified as in Figure.1. All the residential, commercial, industrial customers, renewable energy sources, power converters within the distribution system are shown as lumped blocks for ease and simplicity.

However, much thorough modeling, such as distributed modeling all along the feeders, can also be used. In addition, G(j) is the purchased power in the power industry and provide through the grid in every instant j. Solar energy system and wind energy system provides power S(i) and W(i) to the distribution network. D(i) is the cumulative power provided by the wind and solar energy system. During each instant i. the power balance is created with the residential loads, industrial loads, commercial loads, some local loads, solar–wind energy system generation, and the purchased power. If power is allowed to be given back to the utility grid with net metering scheme, G(j) can be negative, this means that the power is wheeled from the distributed system to the grid. This can be possible, when there is surplus power generated from the solar-wind energy systems connected to the distribution system. For simplification in calculation, power loss is not taken and power levels are assumed to be regulated. Such things are suitable in reliability analysis.

Taking the different component failures in the proposed system, the distributed system integrated with renewable energy sources are operated in grid connected hybrid energy and failure mode of hybrid energy system.

A. GRID-CONNECTED HYBRID ENERGY SYSTEM OPERATION

With the renewable energy sources integration, the load distributor has greater flexibility in the operation. It can use the flexible characteristics of the renewable energy sources to adjust the bidirectional power flow in the grid connected hybrid energy system and adjust the variable renewable power generation. In grid connected hybrid energy system operation, there is less faults in the network [2]. Utility grid can give and take the supply from the renewable energy systems. In this operation mode, bidirectional power i.e. power from the renewable energy resources and power from the external grid can be used to serve the different loads. In smart grid system, new technologies are provided into the grid for better controlling of the grid power. Basically, fuzzy logic and model predictive controlled strategies are proposed to control the grid power. There are many technologies available to control the grid power, but fuzzy logic and model predictive control strategies provide better flexibility and enhancement in the reliability of the system.

Constraints:

i. Controlled rectifier operation constraints

$$0 \leq P_{con}(i) \leq P_{con}max$$
$$0 \leq V_{con}(i) \leq V_{con}max$$
$$0 \leq I_{con}(i) \leq I_{con}max$$

where i = j, j + 1, j + 2,…, j + n

ii. Solar energy system constraints

$$0 \leq S(i) \leq S_{max}(i)$$
$$0 \leq S_{Fuz}(i) \leq S_{fuz,max}(i)$$
$$0 \leq S_{model}(i) \leq S_{model,max}(i)$$

where i = j, j + 1, j + 2,…, j + n. The power required by the loads is equal, less or greater than the power generated from the renewable energy systems. More power can be taken from the renewable energy sources with optimization techniques.

iii. Wind energy system constraints

$$0 \leq W(i) \leq W_{max}(i)$$
$$0 \leq W_{Fuz}(i) \leq W_{fuz,max}(i)$$
$$0 \leq W_{model}(i) \leq W_{model,max}(i)$$

where i = j, j + 1, j + 2,…, j + n. The wind energy system power is given to the controlled rectified circuit followed by the converter and inverter circuit.

iv. Power balancing constraints

$$G(i) + D(i) = R(i) + I(i) + C_m(i) + L(i) \tag{1}$$

$$G_{fuz}(i)+D_{fuz}(i) = R_{fuz}(i)+I_{fuz}(i)+C_{m,fuz}(i) + L_{fuz}(i) \tag{2}$$

$$G_{model}(i)+D_{model}(i) = R_{model}(i)+I_{model}(i) + C_{m,model}(i)+L_{model}(i) \tag{3}$$

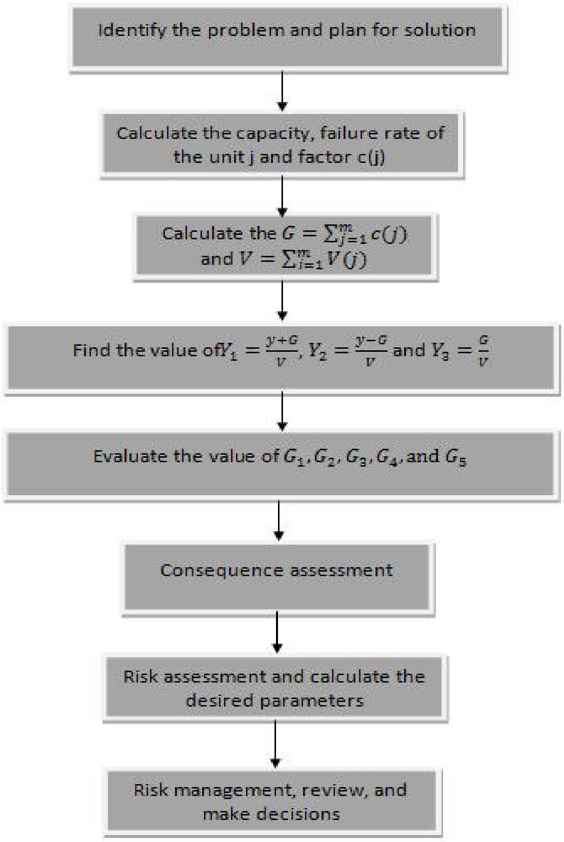

FIGURE 2. Flow chart for alternative model-creating techniques based hybrid energy system risk analysis.

where i = j, j + 1, j + 2,. . . ., j + n. Different types of loads i.e residential, commercial, industrial and local loads, solar energy system power and wind energy system power at the instant I can be known.

Faults:

This article only highlighted the grid connected hybrid energy system. Most of the components of the grid connected hybrid systems are enclosed within the system itself. The drive system is utilized to provide the power from the renewable energy systems. It has wind energy system, solar energy system, controlled rectifier, converter and inverter. The main faults of hybrid energy system includes fault at the gear box, generator faults, open circuit faults, degradation faults, diode faults, fuse faults, equipment's failure, switch device on DC, failure of protective device, phase/line faults, and cable failures as shown in Figure 2.

III. HYBRID ENERGY SYSTEM RELIABILITY ANALYSIS FRAMEWORK

Wind and solar power systems are major and rising sources among the variable renewable energy sources available. The photovoltaic system and wind turbines are extensively used in the distribution systems. These sources are currently connected directly to the power grid at high power level scale with the use of power converters. Different techniques may be used for reliability assessment of grid connected hybrid energy system.

A. ALTERNATIVE MODEL-CREATING TECHNIQUE (AMCT)

Hybrid energy system failures have a discrete distribution and their chances are calculated using the recursive method. It has been observed that if the hybrid energy system is large the failure rates can be calculated by a continuous distribution. Therefore, this assessment approaches the good distribution as the hybrid system size increases. Flow chart for alternative model-creating techniques based hybrid energy system risk analysis is shown in figure.2.

The procedure of knowing the reliability parameters are as follows:

Step 1 Find the value of g(j) for every components in the system

$$g_1(j) = C_j F_j$$
$$g_2(j) = C_j^2 F_j$$
$$g_3(j) = C_j^3 F_j$$
$$g_4(j) = C_j^4 F_j$$
$$g_5(j) = C_j^5 F_j$$
$$V_j^2 = g_2(j) - g_1^2(j)$$
$$V_j^3 = g_3(j) - g_2^2(j)$$
$$V_j^4 = g_4(j) - g_3^2(j)$$
$$V_j^5 = g_5(j) - g_4^2(j)$$

$C_{jand} F_j$ are capacity unit and failure rate of unit j [4].

$$G_2(j) = g_2(j) - 2g_1^2(j) \tag{4}$$
$$G_3(j) = g_3(j) - 3g_1(j)\, g_2(j) + g_1^2(j) \tag{5}$$
$$G_4(j) = g_4(j) - 5g_1(j)\, g_2(j) - 6g_1(j)\, g_3(i) + g_1^2(j) \tag{6}$$
$$G_5(j) = g_5(j) - 5g_1(j)\, g_2(j) - 6g_1(j)\, g_3(j) + 6g_3(j)\, g_4(j) + g_1^2(j) \tag{7}$$

Step 2 Froth the consequences of step 1, find the following factors $G = \sum_{j=1}^{m} c(j)$ and $V = \sum_{j=1}^{m} V(j)$

$$G_2(i) = \sum_{j=1}^{m} G_2(j) \tag{8}$$
$$G_3(i) = \sum_{j=1}^{m} (G_3(j) - 2V_j^3) \tag{9}$$
$$G_4(i) = \sum_{j=1}^{m} (G_4(j) - 3V_j^4) \tag{10}$$
$$G_5(i) = \sum_{j=1}^{m} (G_5(j) - 4V_j^5) \tag{11}$$

Step 3 from the results obtained from the step 2 and for any require capacity components failure

$$Y_1 = \frac{x - G}{V} \tag{12}$$
$$Y_2 = \frac{x + G}{V} \tag{13}$$

According to the value of Y_1 *and* Y_2, four cases are considered.

Case 1 If $Y_2 \leq 1$

Find the values of Y_1 *and* Y_2, under the standard density function, the standard Gaussian distribution S(Z) can be expressed as

$$S(Z) = \frac{1}{\sqrt{2\pi}} e^{-1/2Z^2}, \quad -\infty < Z < \infty \tag{14}$$

$$\text{Area1} = \int_{Z_1}^{\infty} S(Z)\,dZ \tag{15}$$

$$\text{Area2} = \int_{Z_2}^{\infty} S(Z)\,dZ \tag{16}$$

The probability of a component failure is given by = Area 1 + Area 2.

Case 2 If $1 < Y_2 < 0.75$

Find the value of Area1 and Area 2 as in the case 1. In addition, find the value of these factors

$$S_j^2(Z) = (Z_j^2 - 0.75)S(Z) \tag{17}$$

$$S_j^3(Z) = (-Z_j^3 - 1.5)S(Z) \tag{18}$$

$$S_j^4(Z) = (-Z_j^4 + 5Z_j^2 - 10Z_j^3)S(Z) \tag{19}$$

$$S_j^5(Z) = (-Z_j^5 + 8Z_j^2 - 16Z_j^3)S(Z) \tag{20}$$

$$L_j = \frac{1}{8}S_j^2(Z) - \frac{1}{16}S_j^3(Z) - \frac{1}{24}S_j^4(Z) - \frac{1}{32}S_j^5(Z) \tag{21}$$

where j takes the values of 1 and 2.

The probability of a component failure is given by = Area 1 + Area 2 + L_1 + .L_2.

Case 3 If $Y_2 \geq 2.5$

For this condition Area 1 is taken from case 1 and L_2 is taken from case 2.The probability of a component failure is given by = Area 1 + .L_2.

Case 4 If $Y_2 \geq 0.5$

For this condition Area 2 is taken from case 1 and L_1 is taken from case 2.The probability of a component failure is given by = Area 2 + .L_1.

This method presented above for knowing the failure probability of components in the grid connected hybrid energy system has used the two state representation of any component.

Probability of failure of components can be found by calculating the different factors. When a new component is connected or disconnected from the system, new table can be generated using the similar methodology after the new factors obtained.

B. TWO PARAMETERS BASED ALPHA MODEL TECHNIQUE (TPBAMT)

Alpha model is basically a two parameters model which is proposed for reliability analysis in the grid connected hybrid energy system. Flow chart for alpha model technique based hybrid energy system risk analysis is shown in Figure.3.

The associated functions are defined as:

$$O(t) = \frac{\delta}{(c-0.5)!}(\delta_t)^{c-0.5}\frac{e^{-\delta t}}{O(t)} \tag{22}$$

$$O(t) = \sum_{i=0}^{c-0.5} \frac{(\delta_t)^i}{i!} e^{-\delta t} \tag{23}$$

$$F(t) = \frac{\delta}{(b-1)!}(\delta_t)^{b-1}e^{-\delta t} \tag{24}$$

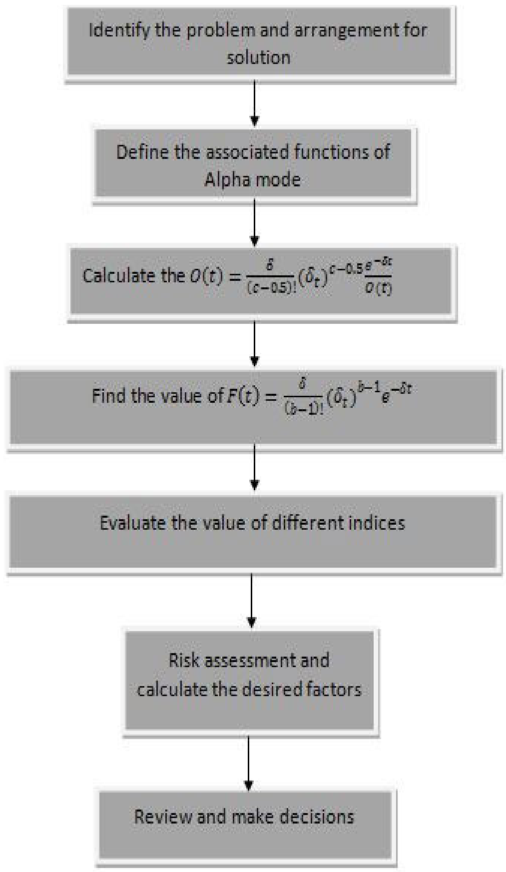

FIGURE 3. Flow chart for alpha model technique based hybrid energy system risk analysis.

where c and δ are positive integer and positive constant respectively.

$$MTTF = \frac{b}{\delta} \tag{25}$$

According to the value of c, two cases are considered.

Case 1 If c > 0.5,

Find the values of $O(t)$ and $F(t)$, O(t) increases in this condition [4].

Case 2 If c = 0.5,

Find the values of $O(t)$ and $F(t)$, for this condition, $O(t)$ shows a constant-hazard rate system.

C. PROPOSED FUZZY FAULT TREE BASED TECHNIQUE (PFFTBT)

For the start up the proposed fuzzy fault tree based technique for evaluation of the reliability analysis of grid connected hybrid energy system, methodology is used and is described in figure 4. Firstly collection of related data, identify the problems and arrangement for solution are executed by observing the complete data, previous data, survey, expert's opinion for the grid connected hybrid energy system. The study reveals that no power or less power output from the hybrid energy system is the top failure in the proposed system. Therefore it is taken as a top event failure. The analysis steps, incorporating all the possibility from the sub events to the top event.

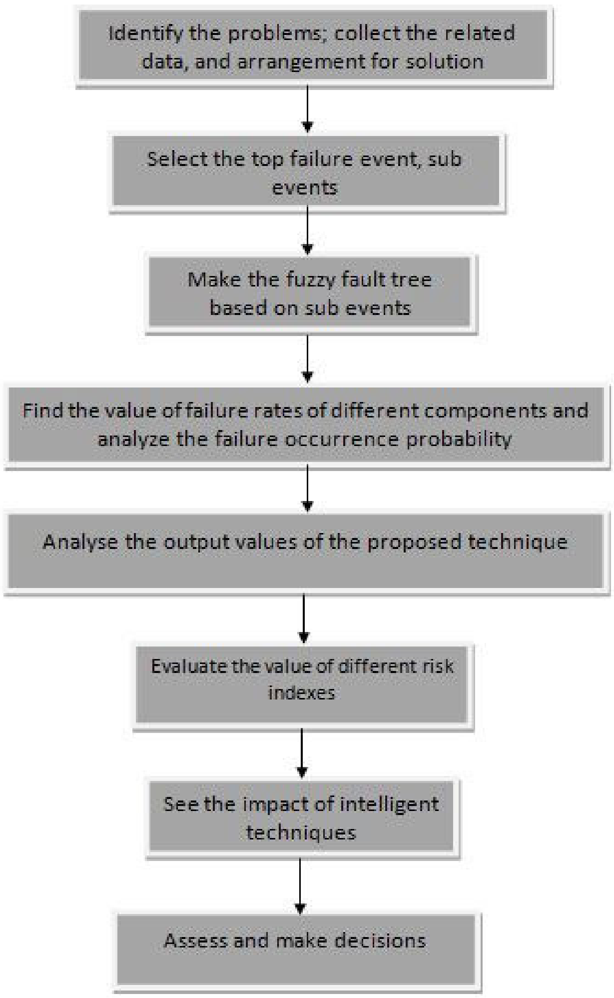

FIGURE 4. Flow chart for proposed developed fuzzy fault tree based hybrid energy system reliability analysis.

TABLE 1. Fault risks and related fuzzy numbers.

Fault Risk	Related Fuzzy Numbers
Extreme Low	(0.01,0.08,0.10)
Nominal Low	(0.12,0.26,0.31)
Less Low	(0.42,0.52,0.61)
Low	(0.45,0.54,0.66)
Sensible Low	(0.48,0.56,0.69)
Sensible	(0.50,0.60,0.77)
Sensible High	(0.65,0.76,0.79)
High	(0.68,0.82,0.84)
Less High	(0.74,0.85,0.92)
Nominal High	(0.82,0.89,0.0.92)
Extreme High	(0.94,0.96,0.99)

Hence, 60 MW hybrid energy systems comprise of 30 MW wind and 30 MW solar energy system has been selected.

Solar and wind energy systems are selected with initially capacity of 30MW each. With the integration of renewable energy sources to the grid, system reliability improves and this makes the system effective.

The data collection are done by accumulating the related data on hybrid energy systems by seeing the old records, knowing solar and wind operation, seeing the impact of intelligent techniques on reliability, and taking the experts views. After knowing the top event, sub event are identified.

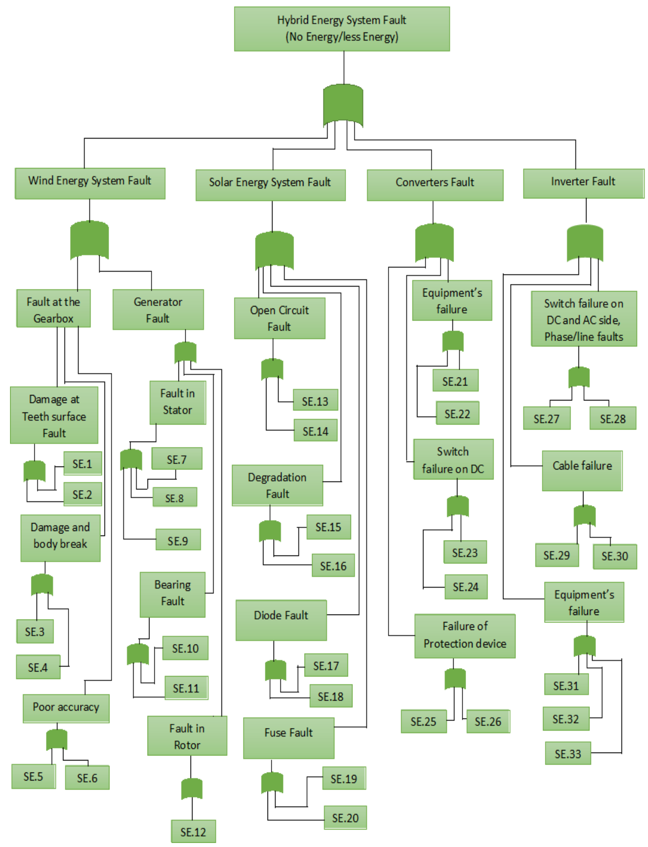

FIGURE 5. Fault tree model of the grid connected hybrid energy system.

TABLE 2. The chance of top event for hybrid energy system.

Alternatives	Probability of top event			Defuzzification		
				Right Score	Left Score	Total Score
H1	0.0278	0.0278	0.0456	0.0367	0.8791	0.0321
H2	0.0265	0.0265	0.0346	0.0356	0.8263	0.0316
H3	0.0254	0.0235	0.0326	0.0342	0.7682	0.0308
H4	0.0234	0.0214	0.0310	0.0326	0.7451	0.0298
H5	0.0135	0.0157	0.0231	0.0312	0.6458	0.0167
H6	0.0125	0.0154	0.0214	0.0307	0.6129	0.0154
H7	0.0124	0.0146	0.0145	0.0301	0.5466	0.0135
H8	0.0113	0.0132	0.0136	0.0245	0.4569	0.0125
H9	0.0109	0.0125	0.0125	0.0213	0.3457	0.0114
H10	0.0102	0.0113	0.0116	0.0156	0.3245	0.0102

The main events failure in the hybrid energy systems are described below:

- Wind energy system faults
- Solar energy system faults
- Converters faults
- Inverter faults

Figure 5 shows the fault tree model of the grid connected hybrid energy system, in this figure, the top event is the hybrid energy systems failure and every systems parts are separated into the sub events.

Table 2 shows the probability of top event with HDFFTBT for different alternatives. The top event chances for the H1 hybrid energy system is 0.0278 0.0278 0.0456.

TABLE 3. Qualitative analysis and failure rates for different assemblies of hybrid energy system.

Top Event	Sub Event	Fault Rate
Hybrid energy system failure (No power or less power)	SE.1: Tensile load	HDFFTBT Based
	SE.2:Gear box fault	0.698 [12]
	SE.3: Contact between the metals	HDFFTBT Based
	SE.4:Involvement of sharp particle in the lubricant	HDFFTBT Based
	SE.5: Error in pitch angle	HDFFTBT Based
	SE.6:Error run out	HDFFTBT Based
	SE.7: Structure	0.705 [12]
	SE.8: Cracking chances	HDFFTBT Based
	SE.9:Slot discharges	HDFFTBT Based
	SE.10: Bearings and shafts	0.563 [12]
	SE.11: Bad handling	HDFFTBT Based
	SE.12:Icing problem on the surface of blade	HDFFTBT Based
	SE.13: PV module	3.2 [1]
	SE.14: Improper caring	HDFFTBT Based
	SE.15: Bad network configuration	HDFFTBT Based
	SE.16: Open contacts	HDFFTBT Based
	SE.17: By pass diode	5.4[1]
	SE.18: Defect in construction	HDFFTBT Based
	SE.19: DC switch	0.2 [1]
	SE.20: Connector failure	HDFFTBT Based
	SE.21:Converter fault	5.9 [1]
	SE.22: Circuit board heating issue	HDFFTBT Based
	SE.23: DC switch failure	HDFFTBT Based
	SE.24: Open circuit between contacts	HDFFTBT Based
	SE.25: Construction problem	HDFFTBT Based
	SE.26: Rating issue	HDFFTBT Based
	SE.27: Electrical stress	HDFFTBT Based
	SE.28: Earth or line Faults	HDFFTBT Based
	SE.29:DC side line faults	HDFFTBT Based
	SE.30:AC side line fault	HDFFTBT Based
	SE.31:Device failure	HDFFTBT Based
	SE.32:Heating issue	HDFFTBT Based
	SE.33: Open or short circuit	HDFFTBT Based

Similarly for the H2 hybrid energy system, the probability of top event is 0.0265 0.0265 0.0346. In the proposed work, the time for risk assessment is selected as 3 years. Table 3 presents the qualitative analysis of the hybrid energy system where 7 sub events failure rates are known and these values are taken from the previous studies [12], [1].

The actual reason in evaluating the fault probability of the hybrid energy system fault is insufficient information of failure of the wind energy system, solar energy system, converters and inverter. Therefore, this problem can be overcome by applying the fuzzy theory. The fault occurrence analysis of all the sub events is done and outcomes are examined to know the sub event chances. The failure rate of the sub events is evaluated and these are taken as fuzzy numbers. Table 4 shows the amassed fuzzy numbers and failure chances of each sub events in the hybrid energy system.

TABLE 4. Amassed fuzzy numbers and failure chances of each subevents in the hybrid energy system.

Sub Event	Amassed Fuzzy numbers	Fault chances of sub events
SE.1	(0.256,0.268,0.367)	2.983E-05
SE.3	(0.356, 0.452,0.531)	3.032E-03
SE.4	(0.045,0.231,0.363)	1.456E-04
SE.5	(0.053,0.174,0.285)	2.648E-07
SE.6	(0.028,0.037,0.126)	6.262E-05
SE.8	(0.058,0.147,0.257)	4.628E-06
SE.9	(0.243,0.258,0.321)	7.825E-05
SE.10	(0.314,0.368,0.425)	6.723E-02
SE.11	(0.153,0269,0.364)	5.935E-03
SE.12	(0.368,0.465,0.673)	2.945E-04
SE.14	(0.523,0.638,0.735)	1.642E-07
SE.15	(0.045,0.244,0.364)	3.469E-05
SE.16	(0.132,0.264,0.384)	2.652E-06
SE.18	(0.256,0.351,0.427)	1.487E-03
SE.20	(0.369,0423,0.576)	8.164E-07
SE.22	(0.254,0.317,0.489)	5.721E-05
SE.23	(0.421,0.527,0.637)	6.283E-03
SE.24	(0.523,0.621,0.731)	2.734E-04
SE.25	(0.346,0.376,0.425)	6.342E-05
SE.26	(0.250,0.378,0.452)	1.925E-07
SE.27	(0.158,0.285,0.365)	7.243E-06
SE.28	(0.105,0.378,0.621)	5.284E-04
SE.29	(0.263,0.432,0.643)	8.237E-02
SE.30	(0.278,0.384,0.431)	2.538E-03
SE.31	(0.154,0.273,0.387)	5.289E-02
SE.32	(0.257, 0.375,0.462)	5.723E-03
SE.33	(0.321,0.452,0.537)	6.734E-04

IV. INTELLIGENT CONTROLLER BASED GRID-CONNECTED HYBRID ENERGY SYSTEM

The selection of the power systems primarily powered by non-conventional energy resources is depended on the necessary and accessibility of the energy resources. The wind-solar energy resources based power supply can support every type of grids and enhancing the reliability of the system. The input of the wind-solar energy sources varies because of the solar radiation and wind speed changes. So, there is a need of proper balancing these fluctuations and to acquire the advanced controller to maintain a good output of the inverter. This problem can be solved by using an advanced control system using the fuzzy logic control and model predictive control schemes.

A. FUZZY LOGIC BASED INVERTER CONTROL FOR GRID-CONNECTED HYBRID ENERGY SYSTEM TO IMPROVE THE RELIABILITY OF THE SYSTEM

The hybrid energy system comprises of solar energy system, wind energy system, boost converter, controlled rectifier and inverter. Inverter can give good power by using an effective control scheme using a fuzzy logic based control system. The fuzzy logic control architecture is developed to build a control algorithm for inverter where error and change of error are selected as input variables and z(k) is selected as output control variable. In steady state condition, error should be minimized because output voltages and reference voltages are very close to each other.

TABLE 5. Fuzzy rules for the proposed controller.

Error → / Change of Error ↓	MN	LN	CN	ZS	MP	LP	CP
MN	MN	MN	LN	MN	CN	MP	ZS
LN	MN	LN	LN	LN	LN	MP	LP
CN	LN	CN	CN	MP	ZS	LP	MP
ZS	CN	CN	CN	MP	MP	LP	LP
MP	CN	ZS	ZS	LP	LP	CN	CN
LP	LN	LN	MP	LP	CP	MP	CP
CP	LP	CN	MP	CP	CP	MP	CP

The four membership functions of trapezoidal type and three membership functions of triangular type are selected as input parameters. The fuzzy set are shown as (MN) more negative, (LN) less negative, (CN) common negative, ZS (Zero), (MP) more positive, (LP) less positive, (CP) common positive, this combination gives the best results. To show the easiness of the control algorithm, fuzzy rules are defined and shown in Table 5.

The ∀ is the inverter output changes and i is the sample time. The fuzzy based duty cycle changes are presented as,

$$\forall = \frac{\sum_{ð=1}^{n} ð4 V_{qrs,i} V_{qref,i}}{\sum_{\in=1}^{n} V_{qref,i}} \tag{26}$$

Inverter side voltage can be defined as

$$\frac{dI_{ac}}{dt} = \frac{V_{ac} - V_{grid}}{¥} \tag{27}$$

Let Y(k) = $V_{ac} - V_{grid}$

Where Iac is the AC side inverter current, Vac is the inverter voltage at phase a before the dq axis conversion, and Vgrid is the required grid side voltage.

By resolving the equations, the value of $Y$is obtained as,

$$Y(k) = 2\left(V_{dref}(k) - V_{qrs}(k)\right) + z(k) \tag{28}$$

Substituting value of Yin to equation 44,

$$\frac{dI_{ac}}{dt} = \frac{2\left(V_{dref}(k) - V_{qrs}(k)\right) + z(k)}{¥} \tag{29}$$

where,

$$\frac{dz(k)}{dt} + \int \frac{3\omega^2}{t} z(t)\,dt = 2V_{dref}(k) - V_{qrs}(k) \tag{30}$$

$$£(t) = \int \frac{3\omega^2}{t} z(t)\,dt \tag{31}$$

By placing the value of $£(t)$ from eq. 31 into eq, 30

$$\frac{dz(t)}{dt} = 2V_{dref}(k) - V_{qrs}(k) - £(t) \tag{32}$$

The state- space model of the fuzzy based inverter controller is defined as,

$$\frac{d}{dt}\begin{pmatrix} V_{qrs} \\ z(t) \\ £(t) \end{pmatrix} = \begin{pmatrix} \frac{-2}{¥} & \frac{1}{¥} & 0 \\ -4 & 0 & -1 \\ 0 & \omega^2 & 0 \end{pmatrix} \begin{pmatrix} V_{qrs} \\ z(t) \\ £(t) \end{pmatrix} + \begin{pmatrix} \frac{2}{¥} \\ 2 \\ 0 \end{pmatrix} V_{dref}(t) \tag{33}$$

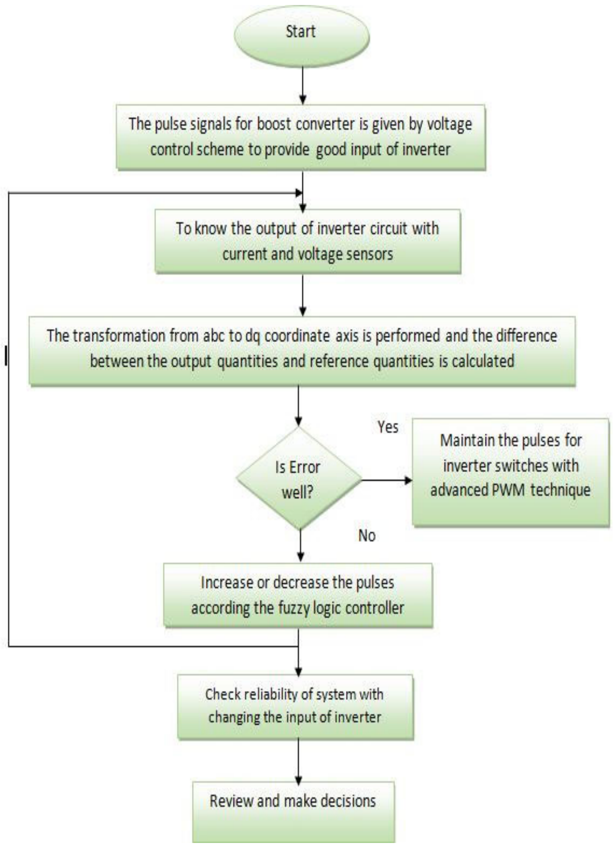

FIGURE 6. Inverter control algorithm flow chart.

The V_{qrs} signal and V_{dref} are transferred to abc frame and in later stage there signals are given to the duty cycle controller circuit to give the signals for the switches in inverter circuit, thus Fuzzy logic controller is applied to lessening the error and advances the system reliability.

B. MODEL PREDICTIVE BASED BOOST CONVERTER CONTROL FOR GRID-CONNECTED HYBRID ENERGY SYSTEM

A simple model predictive control for boost converter is presented in this article for grid connected hybrid energy system to improve the system reliability. The predictive values and value of states are introduced and the control deviation is changed by controlling the desired values in the function according to the error signals. The main steps to be followed for control strategy are defined as, constructing the discrete model for boost converter.Fig.7. shows flow chart of Model predictive control for boost converter.

It can be achieved by discretizing the equations and avoiding the upper order term of period. Further, it is essential to design the objective function of model predictive controller.

$$\sigma = \left((i_b(k+1) - I_{dc,ref}\right)^2 \tag{34}$$

The predictive control value $i_p(k+1)$ is calculated at every instant of time and this value is calculated to decrease the

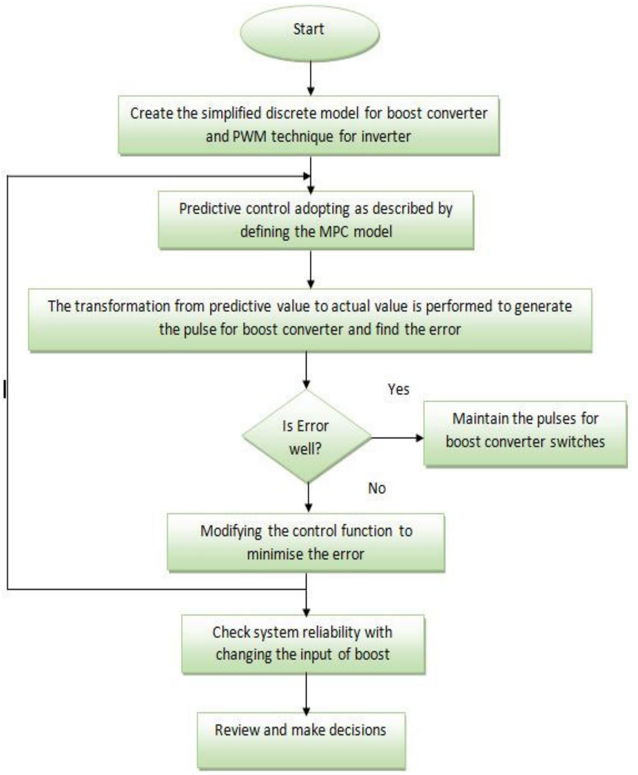

FIGURE 7. Flow chart of Model predictive control for boost converter.

objective function.

$$\frac{\delta\sigma}{\delta i_p(k+1)} = 0 \tag{35}$$

$$i_p\,(k+1) = \frac{SV\,(k) + I_{dc,ref} - i_b}{V} \tag{36}$$

where i_b, $I_{dc,ref}$, S and V are boost converter output current, reference current, switching time and boost converter output voltage.

The modified control value of boost converter current of the next instant can be calculated by reducing the objective function.

$$i_p\,(k+2) = \frac{2SV\,(k) + I_{dc,ref} - i_b - 0.5}{V} \tag{37}$$

Due to the variation in the solar radiation and wind speed, there are some errors. Then the predicted value in the objective function which is based on simple model can be modified according to the error signals.

The optimized state can be defined a:

$$\left(x_{opt}, y_{opt}\right) = arg\,\{\min\sigma(k)\}\,, \quad \text{c(x, y)} \leq 0$$

where, c is the function of inequality and x_{opt} *and* y_{opt} are optimum variables from solving the good value of the prediction in the optimization problem. Further, pulse width modulation technique is used for controlling the inverter.

V. CASE STUDIES

The IEEE reliability test network was provided in order to give a common test network which may be useful for analyzing the outcomes obtained from different techniques. Therefore, a case study on this system is performed to show the effectiveness of the proposed reliability techniques with intelligent control. The risk analysis shows more insights on how the network reliability is changed through the integration of the renewable energy sources into the grid.

In this case study, bus 21 and bus 22 are integrated with wind and solar energy systems. The wind-solar energy systems are operated with proposed techniques and systems are assumed to be good reliable. The faults in the generation are modeled according to the reliability data. The case study horizon is taken as three years and this horizon is replicated for 50 times. The load profile is used as a standard value to avoid the false results.

The risk analysis of the chosen system having solar-wind energy systems with intelligent control technique such as fuzzy logic based inverter control and Model predictive based boost converter control is done. The test system has 12 generating units. The generating capacity of system is 720MW and a total connected load is 650 MW. Total 11 cases are considered to know the exact impact of renewable energy sources integration to the grid on the system reliability.

Case 1: The original system, 30 MW solar system is connected to the bus 21 and 30 MW wind energy system is connected to the bus 22.

Case 2: Addition of 10 MW wind energy system to the original system and it is connected to bus 21.

Case 3: Addition of 10 MW solar photovoltaic system to the original system and it is connected to bus 22.

Case 4: Addition of 20 MW wind energy system to the original system and it is connected to bus 21.

Case 5: Addition of 20 MW solar photovoltaic system to the original system and it is connected to bus 22.

Case 6: Addition of 30 MW wind energy system to the original system and it is connected to bus 21.

Case 7: Addition of 30 MW solar photovoltaic system to the original system and it is connected to bus 22.

Case 8: Addition of 40 MW wind energy system to the original system and it is connected to bus 21.

Case 9: Addition of 40 MW solar photovoltaic system to the original system and it is connected to bus 21.

Case 10: Addition of 50 MW wind energy system to the original system and it is connected to bus 21.

Case 11: Addition of 50 MW solar photovoltaic system to the original system and it is connected to bus 21.

The studied solar-wind energy systems rating range from 60 MW to 160MW and the case 1 is the original case without adding extra wind-solar energy systems and it is first analyzed. Reliability indices which are commonly used are loss of load probability (LOLP), Loss of Load Expectation (LOLE) and Expected energy not served (EENS) for the proposed study including the probability of top event fault occurrence.

By using alternative model-creating technique (AMCT), two parameters based alpha model technique (TPBAMT) and proposed developed fuzzy fault tree based technique

TABLE 6. Reliability indices with fuzzy logic based inverter control for grid-connected hybrid energy system.

S.N.	Proposed Technique	LOLP	LOLE	EENS 10^3 MW	Probability of top event
Case 1	AMCT	0.1836%	67.01	0.625	0.378
	TPBAMT	0.1830%	66.79	0.623	0.376
	HDFFTBT	0.1825%	66.61	0.620	0.373
Case 2	AMCT	0.1815%	66.24	0.618	0.369
	TPBAMT	0.1812%	66.13	0.616	0.367
	HDFFTBT	0.1806%	65.91	0.615	0.365
Case 3	AMCT	0.1798%	65.62	0.614	0.364
	TPBAMT	0.1792%	65.40	0.612	0.363
	HDFFTBT	0.1767%	64.49	0.610	0.362
Case 4	AMCT	0.1762%	64.31	0.607	0.359
	TPBAMT	0.1754%	64.02	0.605	0.357
	HDFFTBT	0.1746%	63.72	0.603	0.356
Case 5	AMCT	0.1724%	62.92	0.598	0.354
	TPBAMT	0.1708%	62.34	0.590	0.352
	HDFFTBT	0.1702%	62.12	0.587	0.351
Case 6	AMCT	0.1698%	61.977	0.568	0.348
	TPBAMT	0.1695%	61.86	0.565	0.346
	HDFFTBT	0.1682%	61.39	0.562	0.343
Case 7	AMCT	0.1679%	61.28	0.559	0.342
	TPBAMT	0.1664%	60.73	0.548	0.339
	HDFFTBT	0.1657%	60.48	0.547	0.336
Case 8	AMCT	0.1625%	59.31	0.539	0.332
	TPBAMT	0.1605%	58.58	0.538	0.328
	HDFFTBT	0.1602%	58.47	0.536	0.326
Case 9	AMCT	0.1598%%	58.32	0.529	0.325
	TPBAMT	0.1587%	57.92	0.528	0.317
	HDFFTBT	0.1569%	57.26	0.525	0.315
Case 10	AMCT	0.1553%	56.68	0.521	0.312
	TPBAMT	0.1536%	56.06	0.519	0.309
	HDFFTBT	0.1512%	55.18	0.514	0.289
Case 11	AMCT	0.1508%	55.04	0.513	0.268
	TPBAMT	0.1504%	54.89	0.509	0.254
	HDFFTBT	0.1487%	54.27	0.507	0.246

TABLE 7. Reliability indices LOLP with changing the load.

S.N.	Proposed Technique	100 % load	120% load	120% load
		Fuzzy logic based control		Model predictive based control
Case 1	AMCT	0.1836%	1.876%	1.875%
	TPBAMT	0.1830%	1.860%	1.854%
	HDFFTBT	0.1825%	1.836%	1.768%

(HDFFTBT) are used, different values for 11 cases are obtained. For the 11 cases, the LOLP, LOLE, EENS and Probability of top event failure are calculated and presented in Table 2.

Different sizes of solar energy systems and wind energy systems are matched and connected in the system to form the different cases. The reliability results for the power system with changing the load in percentage are presented in Table 7,8,9. The study outcomes on table 7, 8 and 9 show the improvement in the reliability. The table 1 shows the reliability is improved with integration of renewable energy sources in the grid, the wind and solar energy systems with higher rating than the case 1 can improve the reliability as this can improve the EENS for heavy systems. With the connection of wind and solar energy systems, the network reliability is more significantly enhanced.

In Table 7, 8 and 9, it can be found that when the load is changed from 100 % to 120% without adding the

TABLE 8. Reliability indices LOLE with changing the load.

S.N.	Proposed Technique	100 % load	120% load	120% load
		Fuzzy logic based control		Model predictive based control
Case 1	AMCT	67.01	684.74	684.37
	TPBAMT	66.79	678.90	676.71
	HDFFTBT	66.61	670.14	645.32

TABLE 9. Reliability indices EENS 10^3 MW with changing the load.

S.N.	Proposed Technique	100 % load	120% load	120% load
		Fuzzy logic based control		Model predictive based control
Case 1	AMCT	0.625	3.750	3.686
	TPBAMT	0.623	3.738	3.729
	HDFFTBT	0.620	3.726	3.714

TABLE 10. Reliability indices LOLP with changing the load.

System Description	Proposed Technique	100 % load	120% load	120% load
		Fuzzy logic based control		Model predictive based control
40MW Wind+30MW solar	AMCT	0.1815%	0.1813%	0.1810%
	TPBAMT	0.1812%	0.1810%	0.1804%
	HDFFTBT	0.1806%	0.1802%	0.1798%
40MW Wind+50MW solar	AMCT	0.1798%	0.1795%	0.1786%
	TPBAMT	0.1792%	0.1767%	0.1754%
	HDFFTBT	0.1767%	0.1765%	0.1735%
50MW Wind+40MW solar	AMCT	0.1762%	0.1760%	0.1754%
	TPBAMT	0.1754%	0.1725%	0.1705%
	HDFFTBT	0.1746%	0.1737%	0.1721%
50MW Wind+50MW solar	AMCT	0.1724%	0.1710%	0.1702%
	TPBAMT	0.1708%	0.1702%	0.1698%
	HDFFTBT	0.1702%	0.1697%	0.1685%
60MW Wind+50MW solar	AMCT	0.1698%	0.1682%	0.1656%
	TPBAMT	0.1695%	0.1683%	0.1654%
	HDFFTBT	0.1682%	0.1675%	0.1638%
60MW Wind+60MW solar	AMCT	0.1679%	0.1665%	0.1628%
	TPBAMT	0.1664%	0.1654%	0.1645%
	HDFFTBT	0.1657%	0.1648%	0.1628%
70MW Wind+60MW solar	AMCT	0.1625%	0.1602%	0.1598%
	TPBAMT	0.1605%	0.1597%	0.1568%
	HDFFTBT	0.1602%	0.1586%	0.1574%
70MW Wind+70MW solar	AMCT	0.1598%	0.1576%	0.1547%
	TPBAMT	0.1587%	0.1543%	0.1528%
	HDFFTBT	0.1569%	0.1525%	0.1517%
80MW Wind+70MW solar	AMCT	0.1553%	0.1502%	0.1499%
	TPBAMT	0.1536%	0.1498%	0.1478%
	HDFFTBT	0.1512%	0.1487%	0.1476%
80MW Wind+80MW solar	AMCT	0.1508%	0.1467%	0.1436%
	TPBAMT	0.1504%	0.1438%	0.1428%
	HDFFTBT	0.1487%	0.1424%	0.1416%

TABLE 11. Reliability indices LOLE with changing the load.

System Description	Proposed Technique	100 % load	120% load	120% load
		Fuzzy logic based control		Model predictive based control
40MW Wind+30MW solar	AMCT	66.24	66.15	66.12
	TPBAMT	66.13	66.05	66.01
	HDFFTBT	65.91	65.65	65.37
40MW Wind+50MW solar	AMCT	65.62	65.68	65.54
	TPBAMT	65.40	65.25	65.16
	HDFFTBT	64.49	64.30	64.15
50MW Wind+40MW solar	AMCT	64.31	64.18	64.11
	TPBAMT	64.02	63.98	63.76
	HDFFTBT	63.72	63.54	63.24
50MW Wind+50MW solar	AMCT	62.92	62.67	62.02
	TPBAMT	62.34	62.15	62.07
	HDFFTBT	62.12	62.07	61.76
60MW Wind+50MW solar	AMCT	61.97	61.46	61.23
	TPBAMT	61.86	61.27	61.16
	HDFFTBT	61.39	61.15	61.12
60MW Wind+60MW solar	AMCT	61.28	61.06	60.96
	TPBAMT	60.73	60.15	60.11
	HDFFTBT	60.48	60.25	60.22
70MW Wind+60MW	AMCT	59.31	59.18	59.12
	TPBAMT	58.58	58.27	58.15
solar	HDFFTBT	58.47	58.38	58.16
70MW Wind+70MW solar	AMCT	58.32	58.17	58.12
	TPBAMT	57.92	57.56	57.46
	HDFFTBT	57.26	57.16	57.05
80MW Wind+70MW solar	AMCT	56.68	56.43	56.35
	TPBAMT	56.06	55.96	55.18
	HDFFTBT	55.18	55.03	54.76
80MW Wind+80MW solar	AMCT	55.04	54.98	54.54
	TPBAMT	54.89	54.56	54.47
	HDFFTBT	54.27	54.16	54.12

TABLE 12. Reliability indices EENS 10^3 MW with changing the load.

System Description	Proposed Technique	100 % load	120% load	120% load
		Fuzzy logic based control		Model predictive based control
40MW Wind+30MW solar	AMCT	0.618	0.614	0.612
	TPBAMT	0.616	0.612	0.610
	HDFFTBT	0.615	0.611	0.609
40MW Wind+50MW solar	AMCT	0.614	0.610	0.607
	TPBAMT	0.612	0.609	0.605
	HDFFTBT	0.610	0.605	0.601
50MW Wind+40MW solar	AMCT	0.607	0.602	0.587
	TPBAMT	0.605	0.603	0.582
	HDFFTBT	0.603	0.602	0.581
50MW Wind+50MW solar	AMCT	0.598	0.586	0.578
	TPBAMT	0.590	0.567	0.562
	HDFFTBT	0.587	0.576	0.573
60MW Wind+50MW solar	AMCT	0.568	0.545	0.542
	TPBAMT	0.565	0.534	0.532
	HDFFTBT	0.562	0.536	0.526
60MW Wind+60MW solar	AMCT	0.559	0.538	0.525
	TPBAMT	0.548	0.532	0.523
	HDFFTBT	0.547	0.542	0.521
70MW Wind+60MW solar	AMCT	0.539	0.533	0.517
	TPBAMT	0.538	0.526	0.515
	HDFFTBT	0.536	0.516	0.512
70MW Wind+70MW solar	AMCT	0.529	0.525	0.521
	TPBAMT	0.528	0.523	0.518
	HDFFTBT	0.525	0.522	0.515
80MW Wind+70MW solar	AMCT	0.521	0.507	0.504
	TPBAMT	0.519	0.515	0.512
	HDFFTBT	0.514	0.512	0.510
80MW Wind+80MW solar	AMCT	0.513	0.511	0.508
	TPBAMT	0.509	0.503	0.501
	HDFFTBT	0.507	0.501	0.487

additional wind and solar energy systems, then it does not improve the LOLE, LOLP, because of the increment in the losses in the load side. Moreover, it reduces the EENS. Table 10,11,12 shows the increment of load from 100% to 120% and integration of more renewable energy source to the grid with fuzzy logic based inverter control, then the LOLE, LOLP and EENS improved.

Similarly, risk analysis of the selected system having solar-wind energy systems with model predictive based boost converter control for grid connected hybrid energy system is done and different results are shown in 7,8,9 and it does not improve the LOLE, LOLP, because of the increase in the losses in the load side. Besides, Table 10,11,12 shows the increment of load from 100% to 120% and integration of more renewable energy source to the grid with model predictive control, then the LOLE, LOLP and EENS improved.

The Renewable Energy Probabilistic Resource Adequacy (REPRA) tool is developed at NREL to know the reliability condition. It gives the value of LOLP of 0.2670%, although this value is quite good but it involves lengthy procedure as comparison with proposed techniques. Whereas, Bulk power system reliability evaluation framework gives the improvement in the reliability indices as presented in [4] with utilization of energy storage device, it gives the value of LOLP and EENS of 0.9386% and 13.84 respectively with 30 MW energy storage + 30MW wind and 0.8700% and 13.67 with 40 MW energy storage + 40MW wind. This technique involves energy storage device which involves higher cost and more losses. The proposed AMCT with Fuzzy logic, TPBAMT with Fuzzy logic, HDFFTBT with Fuzzy logic, AMCT with model predictive, TPBAMT with model predictive and HDFFTBT with model predictive give the value of LOLP and EENS of 0.1836%,0.1830%,0.1825%, 0.1763%, 0.1679%, 0.1672%, 0.625, 0.623, 0.620, 0.567, 0.526, 0.520 respectively. The reliability indices comparison values are shown in Table 13.

As found in the results of the present studies, the connection of wind and solar energy systems within the grid connected system could improve the system reliability, especially when convention power system is connected with the renewable energy sources. However, as the renewable energy sources are operated by system operator locally, so the more cases can be done and improvement in system reliability is achieved. Therefore, techniques for the solar-wind energy system reliability analysis with intelligent control system have been proposed to avoid the safety analysis issues. Results shows that model predictive control system with proposed fuzzy fault tree based technique i.e. (HDFFTBT) gives the better results in comparison with fuzzy based

TABLE 13. Reliability indices comparison table.

Description	Techniques	LOLP	EENS 10^3 MW
60MW System	REPRA Tool [21]	0.2670%	-
30 MW energy storage+30MW wind	Bulk power system reliability evaluation framework [4]	0.9386%	13.84
40 MW energy storage+40MW wind	Bulk power system reliability evaluation framework [4]	0.8700%	13.67
30MW Wind+30MW solar	AMCT with Fuzzy logic	0.1836%	0.625
	TPBAMT with Fuzzy logic	0.1830%	0.623
	HDFFTBT with Fuzzy logic	0.1825%	0.620
30MW Wind+30MW solar	AMCT with model predictive	0.1763%	0.567
	TPBAMT with model predictive	0.1679%	0.526
	HDFFTBT with model predictive	0.1672%	0.520

control system with alternative model-creating technique (AMCT) and two parameters based alpha model technique (TPBAMT).

VI. CONCLUSION

Advanced techniques for grid-connected the solar-wind energy system risk assessment with inexact, scarce information have been given to investigate the practical reliability investigation problem. This article proposes three different techniques i.e. alternative model-creating technique (AMCT), two parameters based alpha model technique (TPBAMT) and proposed fuzzy fault tree based technique (HDFFTBT) with fuzzy logic based inverter control and model predictive based boost converter control for reliability assessment of power system considering the impact of wind-solar energy systems integration into grid.

These techniques have been applied to know the different reliability indices and failure probability of the top event by changing the load. For this study, total 11 cases are considered and reliability indices are calculated for each case. In addition, the fuzzy weighted indices of hybrid systems are calculated with HDFFTB technique and it is taken as the most crucial component of the network failure.

The proposed techniques are wide-ranging and provide less computational burden. Further, obtained outcomes shows that the model predictive control system with proposed fuzzy fault tree based technique (HDFFTBT) gives the better results in comparison with fuzzy based control system with alternative model-creating technique (AMCT) and two parameters based alpha model technique (TPBAMT). Further, the results also shows that addition of the solar and wind energy systems to the grid enhances the reliability of any power system. The analysis presented in this article can proved to be useful in future studies related to planning and expansion of renewable energy integration and penetration into the existing power grid, cost/benefit and revenue analysis of renewable energy integration. The study can also be used to develop business models incorporating renewable energy systems into the existing power system. The manufacture can take this analysis to review and take care of weak system components of the solar-wind energy systems in concern.

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