A Novel Multi-Objective Based Reliability Assessment in Saudi Arabian Power System Arrangement

MOHAMMAD ABDUL BASEER, IBRAHIM ALSADUNI, AND MUHAMMAD ZUBAIR
Department of Electrical Engineering, College of Engineering, Majmaah University, Al Majma’ah 11954, Saudi Arabia

ABSTRACT
In a smart grid power system, reliability performance plays a crucial factor and requires additional focus. Moreover, the integration of Battery Energy Storage (BES) scheme, Solar Photovoltaic (SPV) and wind system in the smart grid system provide significant proficiency and reliability to the utilities. However, the grid coordination with the PV and other resources tends to cause major problems such as power interruption or else power outage. The outage of the power in the grid can cause power loss to the distribution system. Therefore, the novel reliability valuation of the smart grid system is developed for exaggeration of the SPV, wind and BES utilities based on the grid incorporation in Saudi Arabia. Furthermore, a novel Hobbled Shepherd Optimization (HSO) for boost converter control and Multi-Objective Based Golden Eagle (MOGE) algorithm for inverter control is proposed. The execution of this work has been done in MATLAB/Simulink. The simulation outcomes show that the projected method has attained the finest Total Harmonic Distortion (THD) and power loss. Also, the optimal reliability improvement has achieved by the projected methods while compared with the conventional methods in terms of Loss of Load Expected (LOLE), Loss of Load Probabilities (LOLP) and Expected Energy Not Supplied (EENS).

INDEX TERMS
Solar PV array, wind system, battery energy storage, smart grid, optimization, control method, reliability, total harmonic distortion and power loss.

I. INTRODUCTION
In recent times, the PV system and wind-based Renewable Energy Sources (RES) plays an exact eye-catching selection for producing power in the principle electricity stations and rural communities [1]. The reliability of the power system is enhanced by the replacement of conventional power to the alternating RES environment [2]. Consequently, the smart grid working flexibility is improved the conventional system by the SPV and wind-based RES penetration [3]. The reliability of the smart grid is enriched by the power operators as a whole distributed by integrating diverse RES into the conventional power grid. In SPV module and its fittings are the major elements also in the wind system; the gearbox is the main element [4]. In SPV module, the regulation issue and problem in diode is the main fault [30]. The SPV and wind are integrated with the utility grid are termed as on-gird; in addition, if the system is operating as standalone, then it is referred to as off-grid [5]. In rural areas, the utility grid is far away from the rural utilities, and thus off-grid system offers to that areas and attained power by RES system [6]. Hence, this diminishes the need for traditional fossil fuels also evade the issues of acquiring a sufficient amount of fuels in the rural areas [7]. Consequently, the hybrid RES has attained less power price over traditional fossil fuel production [8]. Hence, the off-grid based RES combination attained the finest possibility for power production in rural areas [9]. The grid incorporated hybrid RES system can face several problems such as power conversion method, appropriate site availability, installation as well as maintenance cost [32]. The function of grid incorporated hybrid RES system is significant that mainly based on the pleasant environment of the RES system [10]. However, the large step-up transformer and line filter in the grid system can develop the quality of power problem [11]. Hence, various control methods have developed by various old researches for enhancing the
The conventional control methods in grid system are Hysteresis control (HC), Model Predictive Control (MPC) [12], Proportional Resonance (PR) [13], Sliding Mode Control (SMC) [14], fuzzy logic control [15] and proportional-integral (PI) [16]. Furthermore, the reliability problems have been extensively resolved by different soft computing based optimization methods such as Artificial Bee Colony (ABC) [17], Firefly Optimization [18], Particle Swarm Optimization (PSO) [19], Harmony Search (HS) [20], Gray Wolf Optimization (GWO) [21], Genetic Algorithm (GA) [22], etc. This optimization-based method in the smart grid provides accurate and rapid outcomes. However, in such a situation, the inaccurate rate of regulatory constraints can cause the convergence problem [29]. Also, the uncertainties in the grid coupled hybrid RES like errors, random fault performance and load demand is resolved by the estimation of reliability [23].

Besides, the estimation of the reliability model has been exposed the influence of grid coordination with hybrid RES. However, the particular estimation data is not sufficient for the analysis. Consequently, the old methods have not delivered the optimal outcomes due to insufficient information, computational issues and low performance. Thus, the adequate fluctuation balancing control method is required to regulate the inverter outcomes. Thus, the projected technique is utilized with the advanced optimization method for solving those problems. Hence, this work proposed novel advanced control methods for grid incorporated SPV and wind power system with the estimation of reliability issues. There are two advanced control methods that have been proposed such as HSO for boost converter control and MOGE based controller for inverter system for the estimation of reliability in power system while the influence of hybrid RES in grid incorporation system. Consequently, the power price has been reduced by the multi-objective method.

The structure of this article is summarized as follows: The related work of this research is detailed in Section 2. In Section 3, the modeling of system and problem statement is discussed. The projected control methods in the smart grid system are introduced in Section 4. In Section 5, the simulation outcomes and discussion is explained. As a final point, the conclusion is explained in Section 6.

II. RELATED WORK

Some of the recent researches related to this article are discussed below:

In rural areas, hybrid RES sizing became a critical problem. Moreover, the SPV and wind-based hybrid system and energy storage scheme tend to increase the power price. The demand response in the smart grid can enhance the function of stability, diminish users bills, power profits are increases and investment in system elements. However, the essential load and accessible RES should be balanced by the demand response approaches. For this reason, a new demand response method is developed by Eltamaly et al. [24] for the state of charging as well as discharging power tariff. Here, three various types of optimization are utilized in this work for hybrid RES sizing. The Saudi Arabia northern part rural area data is taken for the modeling and execution.

The development of smart grid requires significant reliable, secure and capability in the power network. Hence, Akhtar et al. [25] developed a different control method for improving the reliability of power system. The impact of grid coupled RES reliability is investigated in this work. The fuzzy logic method has been developed for the inverter control, and the model predictive control method has been utilized for the boost converter control. The significant improvement of this work is the incorporation of diverse intelligent method and reliability calculation.

Barakat et al. [26] developed a hybrid RES with a grid coupled system using a multi-objective PSO (MOPSO) method. The Cost of Energy (COE) and Loss of Power Supply Probability (LPSP) are the two main goals to reduce by MOPSO in SPV and wind-based grid system. Consequently, the third goal is to improve the renewable power fraction of the grid system. The grid installation input is taken from the Ismailia Governorate of rural area in Egypt nation. The outcome shows that the developed method has attained less cost, less greenhouse gas release and improved renewable power fraction. However, economically this method requires more development.

A new model of reliability improvement and estimation is held in the energy system by Gargari et al. [27] in terms of LOLP, LOLE and EENS under the diverse climatic situation. The implementation and reliability estimation has been done by the software MATLAB. Different kinds of power converters are used to improve the significance of reliability in energy systems, and new items are interconnected with the system such as thermal storage, combined heat and power (CHP) component, boiler, Oscillating water column, chiller and electrical storage.

In rural areas, the role of RES plays potential energy to satisfy the electricity demand. Hence, the SPV and wind-based sustainable energy has been developed and integrated with the grid system. However, reliability is a major problem, and so Gbadamosi et al. [28] developed a model of SPV, wind, CHP and energy storage battery for the finest power dispatch in grid system. The reliability indices are estimated based on the fundamental possibility of power from the system. The modeling has been one by the CPLEX solution embedded with the language of arithmetic framework. The performance of the developed method is validated with the consequences of attained reliability. Moreover, the price of the system has been reduced up to 48% while connecting the coordination system to the grid.

From the literature review illustrates that the conventional method has not attained the finest performance in terms of reliability while incorporating with the grid and hybrid RES. Hence, a new methodology is required to improve the overall
system reliability. The foremost contribution of this work is summarized below:

- Initially, the modeling of SPV array, wind power system, BES and loads are incorporated with the utility grid framework is developed using MATLAB/Simulink.
- The smart grid input design for the execution is taken as Saudi Arabia grid coordination model.
- The function of boost converter is controlled by the proposed HSO method in which the parameters of boost converters are regulated by the fitness of HSO algorithm.
- Consequently, the DC bus and AC bus is coupled with the inverter, the performance of the inverter is enhanced by the proposed MOGE control algorithm in which the inverter pulse system is controlled by the fitness of Golden Eagle optimization.
- The proposed Multi-objective algorithm diminishes the power loss, THD and cost of the system.
- Moreover, the projected method has improved the reliability performance of the grid coupled hybrid RES system in terms of LOLE, LOLP and EENS, which is very effective while compared with the conventional methods.

III. SYSTEM MODEL AND PROBLEM STATEMENT

The smart grid system enclosed with the measurement components and smart communication method to regulate the working of the power system and improve the system stability via the demand control method. The system used in the article includes SPV, wind energy, BES, power converters and nonlinear loads. The system model of hybrid RES in grid system is illustrated in Fig.1.

![System model of grid coupled hybrid RES.](image)

**FIGURE 1.** System model of grid coupled hybrid RES.

A. SPV SYSTEM

Due to the irradiance variation can directly influence the generated power from the SPV array [31]. The power from the SPV is improved by tilt the modules of PV, and irradiance increases. Moreover, the power generated from the SPV [33] is estimated by the eqn. (1),

\[ P_{SPV}(t) = S_i(t) \cdot T_a \cdot \eta_{SPV}(t) \]  

where, the optimally tilted solar radiation is \( S_i(t) \), \( T_a \) is represented as the overall area of SPV array and \( \eta_{SPV}(t) \) is denoted as hourly proficiency of SPV array.

B. WIND SYSTEM

Wind energy is measured based on the speed of the wind. The relation of wind energy and speed [34] is expressed in eqn. (2),

\[ P_w(t) = \begin{cases} 0 & V_C < V \leq V_F \\ \frac{V - V_c}{V_F - V_c} \cdot P_p & V_c \leq V \leq V_p \\ \frac{V_c}{V_p} \cdot P_p & V_p \leq V \leq V_F \end{cases} \]  

where the rated speed is denoted as \( V_p \), the wind turbine cut-in speed is represented as \( V_c \) and cut off speed is denoted as \( V_F \).

C. BATTERY ENERGY SYSTEM

While charging or discharging the battery, it losses some energy and it is referred to as self-discharge value. The state of charge of battery is estimated because [35] of self-discharge value is expressed in eqn. (3)

\[ B_E(t + 1) = B_E(t)(1 - \beta) \]  

where \( B_E \) is the battery power.

D. PROBLEM STATEMENT

The RES integration in grid system provides flexibility in the working and bidirectional power flow to the grid system. However, there is a fault and reliability problem that may occur in the grid incorporation system. The incorporation of SPV and wind inputs are changes based on the solar irradiance and speed of the wind. Therefore, a suitable power balancing advanced control method is required to regulate the outcome of the inverter.

1) OBJECTIVES

The reliability of the system is validated by means of Loss of Load Expected (LOLE), Loss of Load Probabilities (LOLP) and Expected Energy Not Supplied (EENS). The indices are explained as follows: The LOLE states that the overall time taken for hybrid RES not capable to give power to the essential load at the time of overall hours in one year. The hours of one year is taken as 8760 hours and the LOLE reliability index is estimated using the eqn. (4)

\[ LOLE = \sum_{j=1}^{8760} P_{outage}(j) \]  

where, the hybrid RES supplied power to the load at hours is represented as \( P_{outage} \). Also, if the loads are not performed, then the value is considered as one or else the value is considered as zero. Consequently, the LOLP is estimated based on the ratio among the rate of LOLE and the overall hours in one complete year. Thus the relation of LOLP with respect to
LOLE is expressed using the eqn. (5).

$$LOLE = \frac{\sum_{j=1}^{8760} P_{\text{outage}}(j)}{8760} = \frac{LOLE \text{ rate}}{8760 \text{ hours}}$$

(5)

Furthermore, the reliable rate of EENS is estimated that states the overall quantity of power is not provided by hybrid RES at the overall year and it is expressed by the eqn. (6)

$$EENS = \sum_{j=1}^{8760} P_{\text{load}}(j) - P_{p,max}(j) \forall P_{\text{load}}(j) > P_{p,max}(j)$$

(6)

where $P_{\text{load}}$ is the load power and $P_{p,max}$ is the maximum power produced at hours.

**IV. PROPOSED METHODOLOGY**

The projected smart grid coordination system includes SPV array, wind energy system, BES, loads, power converters and utility grid. The power produced from the SPV and wind is stored in the BES, while the produced power is more than the essential load power. The BES provides rapid reaction and power usage cost is reduced in smart grid operation. Moreover, the northern part of the Saudi Arabia rural area load data is taken for the design of reliability assessment. The proposed control methods in grid coordinated hybrid RES system is illustrated in Fig.2.

![Proposed control method in grid coordination system.](image)

**FIGURE 2.** Proposed control method in grid coordination system.

In the proposed design, the boost converter of the DC-DC converter is controlled by the novel HSO method along with the MOGE method is developed for the inverter control for improving the reliability of the power system.

**A. PROPOSED BOOST CONVERTER CONTROL**

The function of boost converter has been controlled by the proposed HSO control method. This method is based on the behavior of shepherd optimization. The HSO control method is incorporated with the hybrid RES and grid system to enhance the reliability of the power network. Based on the error rate from the estimated and processes value is taken for the control process. The flow chart of HSO in boost converter is illustrated in Fig.3. The error may occur because of changes in SPV solar irradiance as well as the changes in wind speed. Consequently, the estimated rate in the goal performance depends upon the modified error value. For objective function, the number of particles should be initialized first, and it is considered as $n$ and arbitrarily placed in a group. The initialization is expressed in the eqn. (7),

$$D_{a,b} = D_{\text{min}} + r \times (D_{\text{max}} - D_{\text{min}})$$

where, $a = 1, 2, \ldots, i$ and $b = 1, 2, \ldots, j$, $a$ is the number of groups and individual set of values in a group, $r$ is the arbitrary vector belongs to 0 and 1, $D_{\text{max}}$ and $D_{\text{min}}$ is the maximum and minimum of duty cycle respectively. Then, the overall values in the group are estimated by eqn. (8)

$$bD = i \times j$$

(8)

Consequently, the initial error values in the $i$ groups are chosen depends upon the goal performance rate and arbitrarily provided in the initial column of duty cycle matrix and it regards as the initial function of all group. Then develop the next column of duty cycle matrix, and it is also placed identical to the before step. The function of this placement is repeated in $j$ instant. The duty cycle matrix is articulated in eqn. (9)

$$D = \begin{bmatrix}
D_{1,1} & D_{1,2} & \cdots & D_{1,b} & \cdots & D_{1,j} \\
D_{2,1} & D_{2,2} & \cdots & D_{2,b} & \cdots & D_{2,j} \\
\vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\
D_{a,1} & D_{a,2} & D_{a,b} & D_{a,j} \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
D_{i,1} & D_{i,2} & \cdots & D_{i,b} & \cdots & D_{i,j}
\end{bmatrix}$$

(9)

Each row of $D$ shows that the error of each group; thus, the error of the initial column of duty cycle is the finest one in all groups. The duty cycle in the final position is considered as the worst one in the group. The two vectors have been utilized to estimate the changes of each duty cycle in the group in an identical step size approach. The identical step size is evaluated based on the eqn. (10)

$$\text{step size}_{a,b} = \text{step size}^\text{worst}_{a,b} + \text{step size}^\text{finest}_{a,b}$$

(10)

where $\text{step size}^\text{worst}_{a,b}$ is the aptitude to call a new duty cycle in the exploration area and $\text{step size}^\text{finest}_{a,b}$ is the ability to call the nearby old duty cycle in a potential exploration area. The identical step size of $\text{step size}^\text{worst}_{a,b}$ and $\text{step size}^\text{finest}_{a,b}$ is estimated using eqn. (11) and (12),

$$\text{step size}^\text{worst}_{a,b} = \eta \times r_1 \times (D_{a,w} - D_{a,b})$$

(11)

$$\text{step size}^\text{finest}_{a,b} = \mu \times r_2 \times (D_{a,f} - D_{a,b})$$

(12)

where $r_1$ and $r_2$ are the arbitrary vector that belongs to 0 and 1. $D_{a,w}$ and $D_{a,f}$ is the worst and finest duty cycle in the group in terms of goal performance contrasted with the overall duty cycle value $D_{a,b}$. Then the exploitation and exploration control of duty cycle is calculated by eqn. (13) and (14),

$$\mu = \mu_0 + (\mu_{\text{max}} - \mu_0) \times t$$

(13)

$$\eta = \eta_0 - \eta_0 \times \frac{\text{iteration value}}{\text{Maximum iteration value}}$$

(14)
The $\eta$ value is decreases and $\mu$ increases while increasing the number of iteration $t$. Thus, the exploitation of duty cycle value is increases and exploitation for duty cycle value is neglected. Based on the estimated steps, the new duty cycle is evaluated because if the old duty cycle value is not the finest. The estimation of new value using eqn. (15)

$$D_{\text{new},a,b} = D_{a,b} + \text{step size}_{a,b} \quad (15)$$

After getting the finest duty cycle, the finest pulse is given to the boost converter, and the process will be stopped until it goes to the new step of the iteration.

**B. PROPOSED INVERTER CONTROL**

The projected system enclosed with the SPV, wind, boost converter and inverter. The inverter control provides reliable power to the system using proposed MOGE control method. This control method is developed based on the behavior of the golden eagle. The flow chart of inverter control using the MOGE is illustrated in Fig.5. The error value is given as the input of the MOGE, and the controlled variable is the output. During the controlled process, the basic voltage and output voltage values are almost close, and so the error value is reduced. Initially, the MOGE $m$ randomly choose the error of another MOGE as $n$ and rounds around the finest duty cycle value for away from the $n$ MOGE. The MOGE $m$ selected its circle path and stored its information values. Then it is expressed by the eqn. (16) as,

$$n \in \{1, 2, 3, \ldots, \text{inverter rating size}\} \quad (16)$$

The MOGE is selecting the error and reduce the error in all iteration. Consequently, the target error from the inverter...
The memory value tracking is from the stored memory of the whole group. While recognizing its memory, the new error is high than the old error then the memory renewed that information. The MOGE has tracked the error using eqn. (17)

$$\vec{B}_m = \vec{Y}_g^* - \vec{Y}_m$$  \hspace{1cm} (17)

where $\vec{B}_m$ is the error value tracking, $\vec{Y}_g^*$ high location of reference voltage distant from another point and $\vec{Y}_m$ is the present location of voltage at the point $m$, respectively. Meanwhile, the error tracking directs the size of inverter in MOGE to the high error location, and this shows the exploitation stage of MOGE. Based on the error tracking, the new duty cycle vector is estimated. The duty cycle is a curve vector to the circle as well as perpendicular to the error attack. The duty cycle value can provide the finest pulses to the inverter with respect to error. The $d$ aspects of duty cycle are placed within the curve hyperplane to the inverter surroundings. Initially, the tangent hyperplane is required to estimate for the calculation of the finest duty cycle. The $d$ aspects of hyperplane is expressed in eqn. (18),

$$g_1y_1 + g_2y_2 + \ldots + g_dy_d = e \Rightarrow \sum_{i=1}^{s} g_iy_i = e$$  \hspace{1cm} (18)
If the old error is not estimated, then the new error is predicted. The step vector has been calculated for MOGE $m$ in iteration using eqn. (19),

$$\Delta y_m = r_1 I_a \vec{B}_m + r_2 I_c \vec{D}_m$$  \hspace{1cm} (19)$$

where, $I_a$ is the error tracking coefficient in iteration and $I_c$ is the duty cycle coefficient in iteration, $r_1$ and $r_2$ are the arbitrary vectors that unit belongs to 0 and 1. Also, $\vec{B}_m$ and $\vec{D}_m$ are the Euclidean norm of the error tracking and duty cycle vectors which is estimated using eqn. (20) and (21)

$$\|\vec{B}_m\| = \sqrt{\sum_{n=1}^{s} b_n^2} \hspace{1cm} (20)$$

$$\|\vec{D}_m\| = \sqrt{\sum_{n=1}^{s} d_n^2} \hspace{1cm} (21)$$

The value of $I_a$ and $I_c$ are estimated by the eqn. (22) and (23). Initially, the value of $I_a$ is high and $I_c$ is low after proceeding with each iteration, the value of $I_a$ is increases and $I_c$ decreases. Then it is expressed as,

$$I_a = I_a^0 + \frac{t}{t_{max}} [I_a^{max} - I_a^0] \hspace{1cm} (22)$$

$$I_c = I_c^0 + \frac{t}{t_{max}} [I_c^{max} - I_c^0] \hspace{1cm} (23)$$

where the iteration is denoted as $t$ and maximum iteration is denoted as $t_{max}$, $I_a^0$ and $I_c^0$ are the initial and last rates for the partiality of error, $I_a^{max}$ and $I_c^{max}$ are the initial and last rates for the partiality of duty cycle. The next iteration for the MOGE is estimated by the integration of step vector in the iteration is expressed using eqn. (24)

$$y_{l+1} = y_l + \Delta y_m \hspace{1cm} (24)$$

If the attained fitness value of the new duty cycle is finest than the old duty cycle, which stored in the location of MOGE memory. The new duty cycle value is renewed in its memory. The output voltage and basic voltage is provided to the frame of abc transformation and then the controlled duty cycle signal is provided to the inverter switches using the PWM method. Hence, the proposed MOGE method reduced the error function and this improves the development of reliability in the system. Thus, the required PWM is given to the inverter switches and improves the reliability of the system. Consequently, the cost of the system has been optimized by the eqn. (25)

$$C_m = \frac{1}{N} \sum_{m \in M} \frac{(SPV_{m+1,n} - W_{m,n}) - (W_{m,n} - BES_{m-1,n})}{Cost_{n}^{max} - Cost_{n}^{min}} \hspace{1cm} (25)$$

where $W_{m,n}$, $SPV_{m+1,n}$, and $BES_{m-1,n}$ are the three hybrid RES system integrated in to the grid system to the cost reduction of goal values of the objective function. Once the optimized output is achieved, the process stops the criteria; otherwise, it repeats the function till the finest output has been obtained.

**V. RESULT AND DISCUSSION**

The grid incorporated hybrid RES and the projected control method was executed in mathematical as well as the restrictive programming language of MATLAB/Simulink R2018b platform by means of Intel (R) Core (TM) i5 processor with RAM is 4GB. The simulation parameters for the system model are detailed in Table.1.

**TABLE 1. Simulation parameters for system model.**

| Parameters                  | Value          |
|-----------------------------|----------------|
| SPV array                   |                |
| Solar Irradiance            | 1000 W/m²     |
| Output voltage              | 300V           |
| Maximum power               | 1.2 kW         |
| Wind                        |                |
| Wind speed                  | 2.5 m/s        |
| Cut-in speed                | 7 m/s          |
| Cut off speed               | 22 m/s         |
| Output voltage              | 500V           |
| Maximum power               | 55 kW          |
| Load Rating                 |                |
| Load                        | 9 kW and 11.25 kWAr |
| BES                         | 0.01%          |
| Grid Parameters             |                |
| Grid current and voltage    | 2A and 300V    |
| X/R and power               | 0.7 and 20kW   |
| Real power                  | 1.1 p.u        |
| Reactive power              | 0.288 p.u      |

**A. CASE STUDIES**

The performance of SPV is termed based on the outcomes from the various irradiance stages. The output curve of SPV array under the current with respect to the voltage curve is illustrated in Fig.5. The observation takes place at the various temperature states of the sun and individual cell of the PV array.

Consequently, the SPV array of power with respect to voltage factor under various solar temperatures with the individual cell is evaluated.

The characteristics of power with respect to voltage are obtained. The observation demonstrates that the obtained current, voltage and power values of individual SPV cell beneath various states of solar irradiance such as 0.4kW/m², 0.65 kW/m² and 1.1 kW/m².
The SPV array provided DC link voltage via boost converter controller is represented in Fig.7. This is the outcome of boost converter and the inverter input. Moreover, 250V is given as the input of power inverter. The utmost power of the SPV array is tracked by the proposed HSO controller, and it assists to produce the DC outcome voltage as constant in the boost converter. Furthermore, the power from the SPV is directly given to the grid system. The observed power from the grid current and grid voltage is illustrated in Fig.8. The output power is validated based on the estimation of grid current and voltage.

The one whole year of SPV energy is estimated based on the hourly temperature and solar irradiance. The solar irradiance with respect to the time period of hours is illustrated in Fig.9. The wind voltage from the system is represented in Fig.9. The voltage of wind varies from 400V to −400V. Yet, this voltage as of the wind is in the limit of 400V to −400V during the time period of 0 to 0.1 seconds.

The load at hours and the whole one year is gathered from the remote area of Saudi Arabia northern part, which is illustrated in Fig.10.

The performance of grid coupled inverter under the outcome of grid current and voltage with the least oscillation are extremely difficult. The performance of grid voltage is illustrated in Fig.11. The attained grid voltage from the fig.11 illustrates that the grid voltage has no oscillations and the waveform is in the form of sinusoidal.

The output current of grid performance is illustrated in Fig.12. The observation of figure exposed that the initial stage of the outcome current has small oscillation and later applying the controlled method the current waveform tends to sinusoidal.

The variation of loads in the grid system tends to cause oscillation. The usage of MOGE control method in grid system, the distortion in grid voltage and grid current are
reduced. Thus, the grid voltage tends to sinusoidal and grid current tends to distort at the initial stage.

Consequently, the grid current THD has been attained as 0.21% and power loss of the system is optimized as 0.01MW. The grid current THD is illustrated in Fig.13.

The Grid voltage performance under sag, swell and after control is illustrated in Fig.14. If the grid system faces certain vibrations, then the fluctuations can cause the grid voltage, and it is referred to as grid voltage swell and swag. Consequently, while occuring the sag or swell voltage at the grid end, then the output power of the grid also changes based on the state of voltage swell or sag. The direct as well as quadrature axis voltage also varied because of the grid voltage amplitude variation. Thus, the variation in the system also changes the output voltage of the inverter via PWM methods. The inverter voltage increases while the sag happens in the system; also the inverter voltage diminishes while the swell issue happens in the system. Therefore, the proposed MOGE introduced to control the sag as well as swell in the grid system. The fitness value convergence curve of optimization used in the projected system is illustrated in Fig.15.

The convergence curve shows that the HSO method has attained rapid convergence and obtained the finest outcome after the 25 iterations. Also, the MOGE has obtained the finest solution after the 35 iterations. Hence, the validation of crucial problems is solved by the proposed HSO and MOGE control method. The cost of the traditional system is optimized from $21,235,200 to $1,51,300 by the improved reliability of the system using MOGE method. Moreover, the impact of hybrid RES in grid system has been validated.
The reliability indices of the proposed control method in hybrid RES with grid system is evaluated in terms of LOLP, LOLE and EENS. The Reliability indices with control method for grid integrated hybrid RES is demonstrated in Table.2.

| Case No | Proposed methods | LOLP (%) | LOLE  | EENS (10^3 MW) |
|---------|------------------|----------|-------|----------------|
| 1       | HSO              | 0.142    | 44.01 | 0.321          |
|         | MOGE             | 0.141    | 44.23 | 0.3145         |
| 2       | HSO              | 0.146    | 45.01 | 0.324          |
|         | MOGE             | 0.143    | 44.23 | 0.364          |
| 3       | HSO              | 0.147    | 42.01 | 0.314          |
|         | MOGE             | 0.141    | 41.03 | 0.321          |
| 4       | HSO              | 0.144    | 41.265| 0.317          |
|         | MOGE             | 0.1423   | 42.56 | 0.345          |
| 5       | HSO              | 0.143    | 42.78 | 0.315          |
|         | MOGE             | 0.145    | 41.25 | 0.369          |

### Table 3. Reliability indices under varying the load.

| Reliability indices | Proposed method | 50% load | 100% load |
|---------------------|-----------------|----------|-----------|
| LOLE (%)            | HSO             | 0.145    | 0.234     |
|                     | MOGE            | 0.142    | 0.236     |
| LOLP                | HSO             | 41.2     | 61.25     |
|                     | MOGE            | 41.9     | 64.5      |
| EENS (10^3 MW)      | HSO             | 0.38     | 2.05      |
|                     | MOGE            | 0.31     | 2.06      |

### Table 4. Comparative analysis of the reliability indices.

| Cases               | Methods | LOLE  | LOLP  | EENS (10^3 MW) |
|---------------------|---------|-------|-------|----------------|
| 60kW wind + 8123 kW solar [24] | PSO     | 0.314 | 72.12 | 2.6            |
|                     | Bat     | 0.348 | 76.35 | 2.64           |
|                     | SMO     | 0.354 | 78.12 | 2.86           |
| 50MW wind + 40MW SPV [25] | Fuzzy   | 0.598 | 64.32 | 0.536          |
|                     | MPC     | 0.590 | 64.31 | 0.623          |
| CHP + 15 kW SPV [28] | PSO     | 10.32 | 52.36 | 4.8            |
| 50MW SPV + 50MW wind | HSO (Proposed) | 0.143 | 42.78 | 0.315          |
|                     | MOGE (Proposed) | 0.145 | 41.25 | 0.369          |

Various sizes of SPV and wind system are incorporated to develop diverse cases. The reliability outcome from the Table.2 shows that the hybrid RES with the grid incorporation system reliability has improved significantly. Also, this improved system has enhanced the rate of EENS under heavy
arrangements. The reliability indices under varying the load are explained in Table 3. The load has been varied from 50% to 100% and the grid coupled hybrid RES system along with the HSO and MOGE method has improved the reliability of the system in terms of LOLP, LOLE and EENS, respectively.

### B. COMPARATIVE ANALYSIS

The performance of reliability improvement under the unique case of the proposed HSO and MOGE method is compared with the conventional method in terms of LOLP, LOLE and EENS shown in Table 4. The conventional 60kW wind + 8123 kW solar [24] with PSO, BAT, SMO and 50MW wind + 40MW SPV [25] with fuzzy and MPC also CHP + 15 kW SPV [28] with PSO has been validated the LOLP, LOLE and EENS. Compared with the conventional methods, our proposed system with 50MW SPV + 50MW wind with HSO and MOGE has improved reliability in LOLE, LOLP and EENS values.

### C. DISCUSSION

From the overall outcomes from the result, the proposed HSO and MOGE in grid coupled hybrid RES system have significantly improved the reliability of the power system. The state of the art methods over the proposed system is detailed in Table 5.

### VI. CONCLUSION

In an advanced power system, the hybrid RES with grid system plays a significant option. The hybrid of SPV and wind are the most preferable sources by many developers because the power from these hybrid sources provides sufficient supply to the load. Consequently, the BES is incorporated with the grid system in remote areas. A novel HSO and MOGE method has proposed to control the boost converter and power inverter to improve the reliability of the system. The proposed method in grid system has diminished the THD and power loss as 0.21% and 0.01MW. Moreover, the cost of the system is reduced from $21,235,200 to $1, 51,300 by the improved reliability of the system. The reliability of the system is validated by diverse parameter such as LOLP, LOLE and EENS, respectively. However, compared to the conventional methods, the projected method has attained superior performance in terms of reliability indices. In future, the hybrid deep learning method has been developed for secure reliability enhancement.

### REFERENCES

[1] A. T. Eseye, J. Zhang, and D. Zheng, “Short-term photovoltaic solar power forecasting using a hybrid wavelet-PSO-SVM model based on SCADA and meteorological information,” Renew. Energy, vol. 118, pp. 357–367, Apr. 2018.

[2] O. Ellabban, H. Abu-Rub, and F. Blaabjerg, “Renewable energy resources: Current status, future prospects and their enabling technology,” Renew. Sustain. Energy Rev., vol. 39, pp. 748–764, Nov. 2014.

[3] K. S. Reddy, L. K. Panwar, R. Kumar, and B. K. Panigrahi, “Profit-based conventional resource scheduling with renewable energy penetration,” Int. J. Sustain. Energy, vol. 36, no. 7, pp. 619–636, Aug. 2017.

[4] J. A. Ramos-Hernanz, J. Campayo, J. Larranaga, E. Zulueta, O. Barambones, J. Motrico, U. F. Gamiz, and I. Zamora, “Two photovoltaic cell simulation models in MATLAB/simulink,” Int. J. Tech. Phys. Problems Eng. vol. 4, no. 1, pp. 45–51, 2012.

[5] M. R. Elkadeem, S. Wang, S. W. Sharshir, and E. G. Atia, “Feasibility analysis and techno-economic design of grid-isolated hybrid renewable energy system for electrification of agriculture and irrigation area: A case study in Dongola, Sudan,” Energy Convers. Manage., vol. 196, pp. 1453–1478, Sep. 2019.

[6] G. Zhang, Y. Shi, A. Maleki, and M. A. Rosen, “Optimal location and size of a grid-independent solar/hydrogen system for rural areas using an efficient heuristic approach,” Renew. Energy, vol. 156, pp. 1203–1214, Aug. 2020.

[7] K. Kama, “Resource-making controversies: Knowledge, anticipatory politics and economization of unconventional fossil fuels,” Prog. Hum. Geogr., vol. 44, no. 2, pp. 333–356, Apr. 2020.

[8] M. Ramadhan and A. Naseeb, “The cost benefit analysis of implementing photovoltaic solar system in the state of Kuwait,” Renew. Energy, vol. 36, no. 4, pp. 1272–1276, Apr. 2011.

[9] R. Sen and S. C. Bhattacharyya, “Off-grid electricity generation with renewable energy technologies in India: An application of HOMER,” Renew. Energy, vol. 62, pp. 388–398, Feb. 2014.

[10] M. Rouholamini and M. Mohammadian, “Heuristic-based power management of a grid-connected hybrid energy system combined with hydrogen storage,” Renew. Energy, vol. 96, pp. 354–365, Oct. 2016.
MOHAMMAD ABDUL BASEER received the B.Tech. degree in electrical and electronics engineering from JNTU, India, the M.Tech. degree in electrical power systems, in 2011, and the Ph.D. degree in electrical power systems from KBV University, Barkuchi, India, in 2015. He has worked as a Lecturer with the Chilkur Balaji Institute of Technology affiliated to JNTUH, from 2005 to 2011. He is currently working as a Lecturer with the Department of Electrical Engineering, College of Engineering, Majmaah University, Saudi Arabia. He has published articles in various peer reviewed international journals. His research interests include smart grids, distributed generation, and the grid integration of renewable energy sources.

IBRAHIM ALSADUNI received the B.S. degree in electrical engineering from Western Michigan University, Kalamazoo, MI, USA, in 2010, the M.S. degree in electrical power systems, in 2012, and the Ph.D. degree in electrical power systems from Western Michigan University, in 2019. He is currently working as an Assistant Professor with the Department of Electrical Engineering and the Vice-Dean of academic affairs with the College of Engineering, Majmaah University. He has published articles in various peer reviewed international journals. His research interests include renewable energy sources, smart grids, and system reliability.

MUHAMMAD ZUBAIR received the B.E. degree in mechatronics engineering from NUST, Pakistan, in 2006, the M.S. degree in electrical engineering, in 2010, and the Ph.D. degree in mechatronics engineering from Jeju National University, South Korea, in 2014. He is currently working as an Associate Professor with the Department of Electrical Engineering, College of Engineering, Majmaah University, Saudi Arabia. He has published more than 30 articles in various peer reviewed high IF international journals. His research interests include renewable energy resources, renewable energy systems, and printed electronics.

* * *

M. A. Baseer et al.: Novel Multi-Objective Based Reliability Assessment

IEEE Access, vol. 8, pp. 20965–20976, 2020, doi: 10.1109/ACCESS.2020.2968841.