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Impact of compressed air energy storage system into diesel power plant with wind power penetration

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ABSTRACT

The wind energy plays an important role in power system because of its renewable, clean and free energy. However, the penetration of wind power (WP) into the power grid system (PGS) requires an efficient energy storage systems (ESS). compressed air energy storage (CAES) system is one of the most ESS technologies which can alleviate the intermittent nature of the renewable energy sources (RES). Nyala city power plant in Sudan has been chosen as a case study because the power supply by the existing power plant is expensive due to high costs for fuel transport and the reliability of power supply is low due to uncertain fuel provision. This paper presents a formulation of security-constrained unit commitment (SCUC) of diesel power plant (DPP) with the integration of CAES and PW. The optimization problem is modeled and coded in MATLAB which solved with solver GORUBI 8.0. The results show that the proposed model is suitable for integration of renewable energy sources (RES) into PGS with ESS and helpful in power system operation management.

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1. INTRODUCTION

The RES is intermittent, which makes it more difficult to accurately schedule the power generation from these sources. Whilst the accuracy of WP forecasting has increased substantially in recent years, there are still frequently significant deviations between forecast and actual production capability. Time series is a technique which used for forecasting the wind speed and feed-forward neural network technique is a technique which used for forecasting the solar radiations. Therefore, the forecasting results are used to determine the unit commitment (UC) and optimal sizing of ESS based on the cost-benefit analysis in a microgrid system [1].

A formulation of SCUC with the integration of CAES and WP is presented to obtain a commitment scheduling at a maximum power output and a minimum production cost and the optimization model is formulated as mixed integer programming (MIP)for solving the SCUC [2],[3],[4]. The SCUC problem with the impact of RES and CAES subjected to several unit/system constraints. Unit constraints include power generation limits, on/off time indicator limits, ramping limits, fuel consumption and emission limits. The system constraints include active and reactive powers flow limits on selected transmission lines and voltage limits on buses. The proposed problem is decomposed into a master problem and sub-problem based on Benders decomposition technique to optimizing the system and minimizing the network violations [5].The work in [6] illustrated the thermodynamic analysis of compressed air energy storage with integration of wind power and the results show good performance. The central unit commitment is used to determine the cost benefits of ESS for impacts of large-scale wind power in the Netherlands electricity power supply. The proposed model illustrated the cost benefits analysis and shows that the energy storage can save the operating costs with the increase of WP installation and this can improve the future of the power system layout of the Dutch power generation [7]. The proposed model includes RES integrated with a carbon capture power plant is presented. The robust optimization technique and a stochastic unit commitment with multiobjective optimization models and a linear re-dispatch strategy are employed to obtain the commitment scheduling of units and decrease the emissions [8],[9]. Integration of power-to-hydrogen is one of the solutions for balancing between the supply and the power demand when the PGS contains RES. Ref [10] proposed a model that includes integration of power-to-hydrogen to accommodate a high penetration of wind generation in which the excess wind generation is converting into hydrogen and stored for using later when needed. Ref [12] presented the modern bio-inspired algorithm called Grey Wolf Optimization (GWO) algorithm to solve the proposed problem which includes thermal generators integrated with WP and the optimization problem is formulated as UC model and the results show that the algorithm has an effective capability to obtain the economic benefits with good quality. The uncertainty nature of variable RES makes it difficult to schedule the power generator units efficiently because the system operators depend on variable outcomes. Authors in [12] modify SCUC to capacity constraints by defining scenario response sets for predict the economic cost of dispatching backup capacity when it is needed. The mathematical models and several approaches are developed for addressing renewable power generations effects and uncertainties [13]. This paper introduced the formulation of SCUC problem for power grid system containing DPP, WP, and CAES aims to find the best scheduling of day-ahead operation planning. The rest of the paper is organized as follows: section 2 presents a general description of the system. The mathematical formulation is dealt in section 3. The case studied is explained in Section 4 and the simulation results with discussions are presented in section 5, the conclusion is presented in section 6.

2. SYSTEM DESCRIPTION

The proposed system is composed of several parts includes DPP, WF, CAES and system load demand.

2.1. Diesel Power Plant

The total existing power demands of Nyala city is to about 16 MW and the electrical energy is entirely provided by 14 Diesel Generators with a theoretical maximum capacity of 30 MW. Peak load results in the evening between 19:00h and 22:00h while low load results in the night between 03:00 h and 05:00 h. The fuel cost consumption of DG can be calculated by the quadratic function as:

$$C_f \sum_{t=1}^{T} \sum_{i=1}^{N_G} (aP_{i,t}^2 + bP_{i,t} + c) \tag{1}$$

Where i and t indexes for the time period and diesel unit respectively; a, b and c are the cost coefficients related to DGs fuel consumption carve; C_f is the price of diesel fuel; $P_{i,t}$ is the output power of DG unit (i) at the time interval (t); T and N_G are the total time horizon and the total number of the DGs respectively.

2.2. Wind Power

Wind energy is the source of power which can generate electricity by pushed the wind speed against the fan to convert it to mechanical power then generate electricity. The wind turbine captures the winds kinetic energy in a rotor consisting of two or more blades mechanically coupled to an electrical generator. The turbine is mounted on a tall tower to enhance the energy capture. Numerous wind turbines are located near each other to build a wind farm of the desired power production capacity. The electrical power generated from the wind turbine can be expressed as:

$$P_w = \frac{1}{2} C_p \rho A V^3 \tag{2}$$

where, P_w is the power in the wind (kW), A is the swept area by the blades (m^2), ρ is the air density and it can be taken as 1.225 (kg/m^3), V is the wind speed (m/s) and C_p is the power coefficient of the turbine, which depends on the blades design and the tip speed ratio. The coefficient of efficiency of wind energy conversion to turning the wind energy into energy which can be used, whether electrical or mechanical is the maximum theoretical value for this constant is about 0.593 and known (Betz limit). Thus, the maximum power that can be realized from a wind system is 59.3% of the total wind power [10].

2.3. Compressed air energy storage

The function of CAES is stored energy during the of periods and reused it during the peak periods. There are many applications of CAES in power grid system such as load shifting, mitigate the fluctuations of renewable energies and make management and regulations for the grid system. The main components of the CAES include the compressor, cavern, and the expander. There are two modes of operation, the first mode is the compression mode which the compressor consumed the electricity from wind farm or from the grid system to compress air and stored it in the cavern and the second mode is the generation mode which the air stored in the cavern is heated up by gas and then entered the turbine to generate electricity. Cost of producing $P_{j,t}$ MW of electricity is equal to gas price multiply by heat rate value for generating $P_{j,t}$. It can be represented as:

$$P_{j,t} = \alpha_j^r v_{j,t}^r \tag{3}$$

$$P_{j,t} = -\alpha_j^{inj} v_{j,t}^{inj} \tag{4}$$

where,α_j^r and α_j^{inj} are the efficiency factor for producing power and the efficiency factor for injecting air respectively; $v_{j,t}^r$ and $v_{j,t}^{inj}$ are the amount of released air in MW at hour t and the mount of injected air in MW at hour t respectively.

3. MATHEMATICAL FORMULATION

The mathematical model has formulated a cording to the system parts. As mentioned, the main parts of the proposed system include diesel power generation, wind farm, compressed air energy storage and loads.

3.1. Objective function

The objective function is to minimize the total operation cost consisting of two terms: the first term is diesel operating cost including fuel, startup and shutdown costs and the second term is the operating cost of CAES units throughout the whole operational period. The operating costs of wind power generation units are considered to be zero because wind is free.

$$\min \sum_{t=1}^{T} \left\{ \sum_{i=1}^{N_G} [C_i(P_{i,t}) I_{i,t} + ST_{i,t} + SD_{i,t}] + \sum_{j=1}^{N_C} C_j(P_{j,t}) \right\} \tag{5}$$

where,t,i and j are indexes of time index, number of hours for operating period, diesel units and CAES units respectively; T, N_G and N_C are the numbers of operating hours, diesel units and CAES units; C_i and C_j are production cost functions of diesel unit i and CAES unit j; $ST_{i,t}$ and $SD_{i,t}$ are startup and shutdown costs of unit i at time t respectively;and $P_{i,t}$ and $P_{J,t}$ are output powers from diesel units and CAES units respectively. The unit status indicator $I_{i,t}$ is an integer term can be 1 or zero.

3.2. SCUC constraints

The objective function is subject to several constraints including the unit constraints and network constraints.

3.2.1. System real power balance constraints

The total real power produced by the DG, CAES in addition to power generated by wind turbines is must be equal to system load demand plus losses as expressed by:

$$\sum_{i=1}^{N_G} P_{i,t} + \sum_{j=1}^{N_C} P_{j,t} + \sum_{w=1}^{N_w} Pw_t = \sum_{n \in i} PD_t + PL_t, \quad \forall t \in T \tag{6}$$

where Pw_t and PD_t are the wind power generation and system load demand at time (t) respectively.

3.2.2. Required system spinning and operating reserves

The spinning and operating reserves of the DGs should be large enough to supply electricity to the system during the WP variations as expressed in (7) and (8) respectively.

$$\sum_{i=1}^{N_G} rs_{i,t} + \sum_{j=1}^{N_C} rs_{j,t} \geq R_S(t), \quad \forall t \tag{7}$$

where, $rs_{i,t}$, $rs_{j,t}$ and $R_S(t)$ are the spinning reserve of diesel unit (i) at time (t), the spinning reserve of storage system unit and system spinning reserve requirement at time (t) respectively.

$$\sum_{i=1}^{N_G} or_{i,t} + \sum_{j=1}^{N_C} or_{j,t} \geq O_R(t), \quad t = 1, ...T \tag{8}$$

where, $or_{i,t}$, $or_{j,t}$ and $O_R(t)$ are the operating reserve of diesel unit (i) at time (t), the operating reserve of storage system unit and system operating reserve requirement at time (t) respectively.

3.2.3. Unit ramping limits

Unit ramping up and down limits are expressed as in (9) and (10) respectively.

$$P_{i,t} - P_{i,(t-1)} \leq [1 - I_{i,t}(1 - I_{i,(t-1)})]P_i^{RU} + I_{i,t}(1 - I_{i,(t-1)})P_{i,min} \tag{9}$$

$$P_{i,(t-1)} - P_{i,t} \leq [1 - I_{i,(t-1)}(1 - I_{i,t})]P_i^{RD} + I_{i,(t-1)}(1 - I_{i,t})P_{i,min} \tag{10}$$

where P_i^{RU}, P_i^{RD} and $P_{i,min}$ are the ramp-up, ramp down and minimum generation limits respectively.

3.2.4. Real power generation limits

The real power of each unit are restricted by the lower and upper limits as expressed in (11).

$$P_{i,min} \leq P_{i,t} \leq P_{i,max} \tag{11}$$

where $P_{i,max}$ is the upper limit of real power generation of unit i.

3.2.5. Minimum On/Off time limits

Unit minimum on and off time limits are expressed in (12) and (13) respectively.

$$\begin{cases} T_i^U = max(0, min(N_T, (T_i^{on} - X_i^{on})I_i)) \\ \sum_{t=1}^{T_i^U}(1 - I_{i,t}) = 0 \\ \sum_{\tau=t}^{t+T_i^{on}-1} I_{i\tau} \geq T_i^{on}(I_{i,t} - I_{t(t-1)}) \qquad \forall t = T_i^U + 1, ..., N_T - T_i^{on} - 1 \\ \sum_{\tau=t}^{N_T}[I_{i\tau} - (I_{i,t} - I_{t(t-1)}] \geq 0 \quad \forall t = N_T - T_i^{on} + 2, ..., N_T \end{cases} \tag{12}$$

$$\begin{cases} T_i^D = max(0, min(N_T, (T_i^{off} - X_i^{off})(1 - I_i))) \\ \sum_{t=1}^{T_i^D}(I_{i,t}) = 0 \\ \sum_{\tau=t}^{t+T_i^{off}-1} (1 - I_{i\tau}) \geq T_i^{off}(I_{t(t-1)} - I_{i,t}), \quad \forall t = T_i^D + 1, ..., N_T - T_i^{off} - 1 \\ \sum_{\tau=t}^{N_T}[1 - I_{i\tau} - (I_{t(t-1)} - I_{i,t})] \geq 0, \quad \forall t = N_T - T_i^{off} + 2, ..., N_T \end{cases} \tag{13}$$

where T_i^{on} and T_i^{off} are the minimum on/off time of unit i respectively; T_i^U and T_i^D are the hours of unit i must be initially on/off due to its minimum up/down time limits respectively; X_i^{on} and X_i^{off} is number of hours of unit i has already been on/off prior to the first hour respectively.

3.3. Constraints for CAES

As mentioned, CAES has two modes of working (the compression and the expansion modes). Three working modes of CAES are considered, the compression mode which CAES acts as a load, the expansion mode which acts as a generator and an idling mode which CAES is not operating as compression or expansion modes. To integrate the CAES in the proposed system with three mentioned modes, it should consider these integer variables as in (14).

$$I_{j,t} + I_{j,t}^c \leq 1, \quad \forall j, \quad \forall t \tag{14}$$

where,$I_{j,t}$ is 1 in a generation mode and 0 is either idle or compressor mode; $I_{j,t}^c$ is 1 in compressor mode and 0 is idle mode.

The amount of injected air in MW at hour t and the amount of released air in MW at hour t are limited by its maximum and minimum capacities are expressed in (15) and (16) respectively.

$$v_{j,min}^r \leq v_{j,t}^r \leq v_{j,max}^r \tag{15}$$

$$v_{j,min}^{inj} \leq v_{j,t}^{inj} \leq v_{j,max}^{inj} \tag{16}$$

Where, $v_{j,min}^r$ and $v_{j,max}^r$ are minimum and amount of released air in MW while $v_{j,min}^{inj}$ and $v_{j,max}^{inj}$ are the minimum and maximum amount of injected air in MW respectively.

In the compression mode, the amount of compressed air is limited to the maximum capacity of the cavern minus the current inventory level as expressed in (17) and (18) respectively.

$$\beta_{j,t+1} = \beta_{j,t} + v_{j,t}^{inj} - v_{j,t}^r, \quad \forall j, \quad \forall t \tag{17}$$

$$\beta_{min}(j) \leq \beta_{j,t} \leq \beta_{max}(j), \quad \forall j, \quad \forall t \tag{18}$$

where, $\beta_{j,t}$ and $\beta_{j,t+1}$ are the inventory level at time t and inventory level at time t+1, while $\beta_{min}(j)$ and $\beta_{max}(j)$ are the minimum and maximum capacity of the cavern in MWh respectively.

The mathematical model of the proposed system is a decision problem with an objective function to be minimized with subjected to many of equality and inequality constraints. The simulations were coded in MATLAB with GUROBI 8.0.0 solver, using a 2.20 GHz processor with 4 GB of memory and 64-bit operating system.

4. CASE STUDY

The case studies are performed using the data of Nyala DPP and nyala WF with the integration of CAES to obtain the operation scheduling of the system. For the WF, the total generation capacity is 20 MW produced by several turbines unites with rated power 1.500MW and 1800 MW; cut-in and cut-off wind speed are 4 m/s and 25 m/s respectively. The parameters of LD and WP forecasted for one day are listed in Table 1. For the Nyala DPP, the electricity is generated by 14 DGs with the total capacity of 30 MW as listed in Table 2. The CAES has a maximum and minimum generation capacity of 15 MW and 3 MW respectively. There are three cases studied is performed. The first one is only Nyala DPP is used to supply the LD; the second one is the integration of Nyala WF into Nyala DPP to supply the LD by the sharing power and the third case is the integration of CAES instead of WF where there is no wind available.

Table 1. Forecasted Load Lemand and Wind Power

Time (Hour)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
wind (MW)	17	9	10	15	18	13	11	12	18	19	20	17	15	9	6	4	3	3	3	5	7	8	6	10
load (MW)	22	14	15	20	23	19	21	24	29	28	29	27	29	22	18	16	14	14	9	22	23	21	17	16

Table 2. Diesel Generators Parameters of Nyala Power Plant

Units	Pmax (MW)	Pmin (MW)	c ($/h)	b ($/kw)	a ($/$kw^2$)	Min On	Min Off	ST	Ramp Up
G1	1.600	0.480	37.2832	0.135318	0.00003056	3	-2	70	20
G2	1.600	0.480	44.0064	0.15005	0.000018336	1	-1	30	20
G3	1.876	0.562	23.5312	0.137826	0.00006112	1	-1	30	20
G4	1.876	0.562	11.9183	0.202613	0.000006112	4	-2	100	40
G5	1.876	0.562	31.1712	0.161051	0.000021392	3	-2	80	25
G6	1.200	0.480	58.9808	0.166858	0.000006112	3	-2	80	25
G7	1.200	0.480	16.1968	0.187944	0.000009168	5	-2	200	50
G8	3.520	1.408	37.2832	0.135318	0.00003056	4	-3	95	35
G9	3.520	1.408	44.0064	0.15005	0.000018336	4	-2	95	30
G10	1.840	0.552	23.5312	0.137826	0.00006112	3	-2	70	20
G11	1.840	0.552	11.91834	0.202613	0.000006112	1	-2	30	20
G12	2.640	0.792	31.1712	0.161051	0.000021392	1	-1	30	20
G13	2.640	0.792	58.9808	0.166858	0.000006112	4	-1	100	40
G14	2.640	0.792	16.1968	0.187944	0.000009168	3	-3	80	25

5. RESULTS AND DISCUSSION

There are three cases are discussed in this section: the first one is the basic case which the system load is supplied by the DPP only; the second one is the integration of the wind power into DPP without CAES system, and the third one is the integration of CAES into DPP when the wind power is not available.

5.1. Case I: The normal operation of diesel power plant without integration of the wind power and CAES

In this case, the operation schedule is determined for the DPP as a basic supply the load without integration of wind power and CAES during the day-ahead period and the simulation results are shown in Table 3. The results show that, during the dispatched period only the cheaper generator units are committed to supplying the load while the expensive generator units G1, G4, G7 and G10 can not generate any power during the first seven hours and then started to produce electricity during the period 9:00-13:00 and then turn off again during the period 14:00-24:00. The operation cost is very high because the operation cost only depending on the diesel and the total operating costs are equal to $114740.

Table 3. Nyala Diesel Power Plant only

	Hours																							
Units	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
G1	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
G2	1	0	1	1	1	0	1	1	1	1	1	1	1	1	0	0	0	0	0	1	1	1	0	0
G3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	0	1	1	1	1	1
G4	0	0	0	0	0	0	0	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
G5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
G6	0	1	0	1	1	1	1	0	1	1	1	1	1	0	1	0	1	1	1	0	1	1	1	0
G7	0	0	0	1	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
G8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1
G9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
G10	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
G11	1	0	0	0	1	1	0	1	1	1	1	1	1	1	0	0	0	0	0	1	1	0	0	0
G12	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
G13	1	0	0	0	1	0	1	1	1	1	1	1	1	1	1	0	0	0	0	1	1	1	0	0
G14	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	1	1	1

5.2. Case II: The operation of the system with diesel power plant and wind power integration

This case explained the integration of wind power into the diesel power plant to serve the load by the shared power and the results are shown in Table 4. From the results, all the expensive generator units G1, G2 G4, G7, G10, G11, G13 are turned off during the whole operation period and the load demand can be supplied by the other cheapest generators only. The total operating costs is equal to $45576 and this cost is less than the first case because the expensive generator units are substituted by the wind power to serve the load.

Table 4. Nyala Diesel Power Plant with Wind Power

	Hours																							
Units	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
G1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
G2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
G3	0	0	0	0	0	0	0	0	1	0	1	0	1	1	0	0	1	1	0	1	1	1	1	0
G4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
G5	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
G6	0	0	0	0	0	1	1	1	1	1	0	1	1	0	1	1	1	1	0	1	0	0	1	1
G7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
G8	0	0	0	0	0	0	1	1	0	1	0	1	1	1	0	1	0	0	0	1	1	1	0	0
G9	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
G10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
G11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
G12	0	0	0	0	0	0	0	1	1	0	1	1	1	1	1	1	1	1	0	1	1	1	1	0
G13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
G14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0

5.3. Case III: System operation with diesel power plant and impact of compressed air energy storage system

This case explains the performance of the proposed system when CAES is charged by using the excessive power from the wind during the off-peak period and then discharge it when there is no wind power during the peak period and the simulation results are shown in Table 5. As shown in the results, the generator units G1, G4 and G10 are turned off during the whole operation periods because they are expensive while the other generator units are committed except units G7 and G11 are committed only at 9:00 and 8:00 respectively. The total operating costs in this situation are \$45576 and this cost is relatively high compared with the second case because the capacity of energy storage system is less than the capacity of the wind farm.

Table 5. Nyala Diesel Power Plant with Battery Energy Storage

	Hours																							
Units	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
G1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
G2	1	0	0	0	0	0	0	0	1	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0
G3	1	0	0	0	1	0	1	0	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1
G4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
G5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
G6	1	0	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	0	1	1	1	1	1
G7	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
G8	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	0
G9	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
G10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
G11	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
G12	0	1	0	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	0	1	1	1	1	1
G13	0	0	0	0	0	0	0	1	0	1	1	0	1	0	0	0	0	0	0	1	1	0	0	0
G14	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0	0	1	1	1	1	1

6. CONCLUSION

The hybrid system includes diesel-wind-CAES has been Modeled and simulated to obtain the operational planning of the proposed system. From the simulation, its observed that the integration of wind farm into diesel power plant is the best choice for minimizing the use of fossil fuels as well as decreasing the greenhouse emissions such as CO_2. The CAES plays an essential role in the hybrid system to mitigate the variability nature of the wind energy by storing the excessive wind energy during the off-peak period and reused it during the peak period. Thus the proposed system is useful for helping in integrating renewable, backup system and make management for the grid system.

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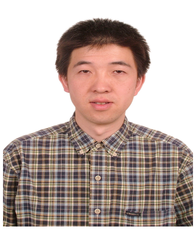

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