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Design and Simulation of Smart Grid Based on Solar Photovoltaic and Wind Turbine Plants

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ABSTRACT

The objective of this paper is to design a smart grid of an ordinary plant with two renewable resources (solar PV and wind turbine) plants. The burnout of fossil fuels globally has created a hasty need for alternative energy sources to meet current energy demands. To address this issue, a hybrid power system has been developed, which combines clean energy sources, such as solar PV and wind, with fossil fuel generators, power conditioning systems and energy storage systems. This hybrid system adduces higher efficiency, more flexibility in environmental and planning benefits compared to relying solely on diesel generators. However, employing solar and wind energy has the disadvantage that they are erratic and dependent on climatic and meteorological variations, which may not coincide with the timing of energy need. This not only has an influence on the system's functionality but also causes batteries to be disposed of too soon. The results illustrated the root mean square (r.m.s) power behaviour over a 24 hour each day in May, 2020 according to the weather climate in Mosul city. Finally, it has been confessed that the individual power generated either by solar PV or by wind turbine was enough to supply the load.

1. INTRODUCTION

The growing need for traditional energy sources such as charcoal, natural oil and gas is driving individuals to explore and advance renewable energy sources or alternative energy sources. Wind and solar power, for example, have become well-established, cost-effective, and frequently used clean energy sources [1]. These energy sources are not harmful to the environment. Hybrid energy systems combine two or more renewable energy sources, such as solar, hydro power and wind to provide a clean and environmentally beneficial energy supply. These hybrid systems can function independently or in conjunction with the power grid [2]. Grid-connected hybrid systems are more dependable in terms of supplying nonstop power to the grid because any power shortages or issues with renewable energy sources can be compensated for by connecting directly to the grid. A hybrid power system collects two renewable energy sources, wind and solar energy, as sources of input [3]. A wind turbine turns mechanical energy into electrical energy by producing an alternating current output voltage, which is then converted to DC using an AC/DC converter or rectifier. A photovoltaic cell is a device that changes light energy into electrical energy. The hybrid wind and PV system is grid-connected delivers a steadier supply to the load [4]. If any of the energy sources fail, the loads can be linked to the grid. The primary goal of this study is to develop a model for a grid-connected wind hybrid and solar power system. The based on the inputs of solar radiation and wind speed, this model calculates the outputs of these two sources. Both the PV system and the wind system are modelled, and the output of the system is analysed [5]. It is vital to identify alternate sources of energy in order to satisfy the increasing need for energy while reducing negative environmental consequences. Recent renewable energy development and research has shown significant promise as a supplement of traditional power generation systems [6]. Renewable energy sources such as wind energy, solar energy, or micro-hydro-power have immense promise for providing reliable power to isolated regions. The plentiful energy plenteous in environment can be collected and changed to electricity in a containable manner to meet the required power request and, as a result, increase the living conditions of those outside arrival to the electricity grid [7]. The benefit of utilizing renewable energy for power generation on distant islands are evident, given the high expense of importing fossil fuels and growing worries about changes in the climate and global warming. The difficulty in managing output power to satisfy varying load needs owing to daily and seasonal patterns of renewable energy supply is one disadvantage of standalone renewable energy power systems. In addition, a substantial initial capital expenditure is necessary [8]. This study titles the integration of solar wind systems for the creation of possible power. Sun energy varies with changes in sun irradiation on an hourly, daily, and monthly basis. Under various conditions, wind turbine power output differs with wind speed [9]. However, one common disadvantage of wind and energy of solar selections is their unpredictability and reliance on climatic and weather swings, and differences in wind and solar energy might not correspond the time distribution of load requirement [10]. The numerous and ground-breaking inventions that have been made thus far and that people are continuing to create for the benefit of nations and continents were inspired by the flight of birds, the shapes of plants, the colour of flowers, the sprouting of waters, and other natural wonders. The concept of "organic architecture" encourages harmony between the natural and manmade worlds [11]. It attempts to comprehend and accommodate the terrain through design, from major territorial development plans to minor supplementary works in private or public contexts. Larger constructions, such as houses, furniture, and surrounding structures, provide favourable situations for them to combine into a cohesive composition [12]. Figure 1 represents a smart grid uses solar PV/wind turbine as support supply with ordinary plant.

Figure 1. General outline of smart grid

In the first work, they applied the hybrid solar PV and wind turbine system to supply the load but they entered the effect of super capacitor system to overcome the fluctuation and to support the load at peak period and at absence the sunlight or wind speed. In the second work, they simulated the hybrid system on Matlab/Simulink of a whole day regardless the presence effect of solar sunlight wind speed during the day. The difference between the own work and the two last works in the time period along the day. The novelty of the proposed smart grid, a climate effect was added according to Mosul-Iraq city for one season. The period of sunlight (peak sun hour) and the wind blowing of a whole day was adopted. A time interval was divided into four sectors each sector includes 6 hours. The load and the individual loads were coverage according to the time sectors.

2. LITERATURE REVIEW

Bankar and Tibude [13] studied a hybrid power-generating simulation analysis that employs a unified control strategy to improve power quality. The integrated control technique is utilized to address challenges caused by nonlinear local loads.

Kumar et al. [14] focused on a grid integration and quality of power challenges connected to the renewable energy systems integration into the grid, as well as the roles of electronic power devices and flexile AC systems of transmission in these issues. It too highlights contemporary advancements in electronics of power for integrating photovoltaic and wind power generation.

Patel and Bhuria [15] studied the numerous quality of power challenges and the solutions for overcoming these issues through the use of Grid-connected hybrid power generating.

Radwan et al. [16] worked on effective and simple wind-photovoltaic cogeneration system that is grid-connected. voltage source converters (VSCs) with back-to-back (BtB) connections connect a full scale wind turbine powered by a permanent magnetic synchronous generator to the utility grid.

Verma et al. [17] presented the difficult consistency of the PV and wind turbine power system connected to the grid. The energy storgy system based on the super capacitor is used to reduce the fluctuation of the linked grid system. A control approach is also suggested in order to maintain the equilibrium process and obtain the most power from hybrid grid connected system.

Bhardwaj and Majumdar [18] focused on the smart grid integration of solar PV and wind turbine hybrid system grid. The existing wind system have scope of adding solar PV capacity. A PV/WT hybrid power system is constructed and modeled in this work for smart grid applications Matlab/Simulink software. It has beed concluded that the designed system and its control approach function admirably in the simulation of a whole day.

The smart grid is capable of feeding the total load during the 24-hour period with existence of (solar PV and wind) energy in addition to the ordinary supply, as well as feeding the solar loads individually and the wind loads individually during the sun arc and wind blowing hours' design and rating for solar and wind transformers cover the loads during may month 2020.

3. MATERIALS AND METHODS

Due to adverse weather, ceaseless power flow for stand-alone loads can't be assured if one of the components, like a wind turbine or a PV array, is not operational. At this level, fuel cells can meet the load requirements of solar PV and wind turbines by providing ceaseless power to the load [19]. To eliminate power variations from wind and solar PV turbines, the proposed system model is imitated by an efficient energy device fuel cell. Wind produces the most electricity, implying that wind is superior to solar at this location. However, neither can bear the strain on their own. According to this article's review, an optimal wind and solar PV system of hybrid is more less expensive than a solar PV alone system. Pre-charging enables load impedance tests prior to powering on and two-step charging reduces flow currents [20]. Configuration of a hybrid energy system, when solar photovoltaic and wind turbine generators are combined with storage technologies to offset plant output fluctuations, considerably higher generating capacity factors can be achieved. The electrical energy produced by the solar panels and wind turbines must be turned into easily stored battery or capacitor energy in order to provide continuous power [21]. This requires an efficient energy storage system. Although power fluctuation can be removed and the hybrid system operates well, ceaseless power flow to stand-alone loads cannot be secured due to the deficiency of energy vastness of storage systems, especially under worst climatic conditions or when absence the generated power from the hybrid system [22]. allowing for the charging of individual batteries to learn about the fundamentals of hybrid power generation utilize wind and PV energy systems.

- Conducting a literature search to identify flaws with the conventional system.
- An examination of the proposed technique.
- Research control strategies.

4. SMART GRID UNDER STUDY

The proposed smart grid located virtually in Mosul city, which is located in Iraq at latitude 36.3° and longitude 43.13°. The smart grid is made up of solar PV (5 kW) and wind turbines (3 kW), which are represented by three winding transformers as a source of electricity for the remote loads that are linked to these renewable facilities. Figure 2 depicts a smart grid diagram.

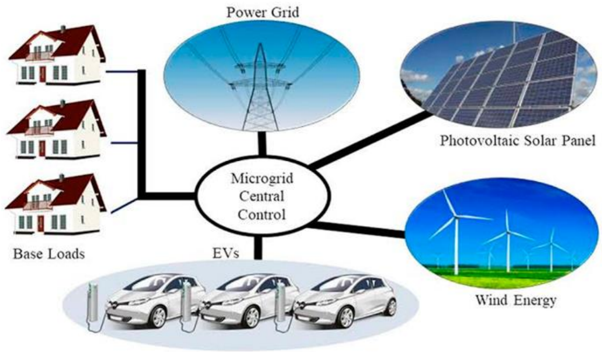

Figure 2. Smart grid under study

4.1 Data and methods

The current work involves tests that employ live data from an operating smart micro grid as a source. The following information was measured and collected: Power demand (kW), solar irradiation (W/m^2), wind speed (m/s) and the bank of batteries DC voltage (V) Data was gathered across two distinct time periods. Mosul weather forecast for May 2020.

4.2 Solar irradiance

The investigated smart grid generates electricity mostly through photovoltaics. Solar irradiance was measured as universal horizontal irradiance (GHI) and on-site recording with a Symphonies LI-COR LI-200/R-BL pyrometer [23].

4.3 Wind climate

Wind represents the flow of air through the earth's surface, which caused by atmospheric pressure changes. The worldwide atmospheric circulation pattern is governed by temperature changes, specially the difference between the poles and heating at the equator, as well as the earth's rotation. The wind climate Because of its geographical location, the town under consideration has high wind potential [24]. Wind speed and direction were measured at the site between 4 and 36) km/h in May 2020.

5. SYSTEM DESCRIPTION

The smart grid system is divided into three layers: control layer, physical power layer, and application layer. According to Katherine Hamilton, the grid of grid-smart must also be dynamic and maintain constant communication of two ways. When PV panels are put on rooftops, Intelligent building systems, for example, will create, store, and consume their own energy [25]. As a result, they are now active smart grid structures. Energy may be conserved, and dependability and transparency may improve. This section describes a model of dynamic simulation for a solar PV and wind turbine hybrid power system. The created system comprises a PV array DC to DC converter, and an insulated transformer designed to attain the maximum power point (MPP) [26]. The circuit schematic of the combined solar and wind turbine system and the transformer specifications of PV and wind turbine are listed in Table 1.

Table 1. The transformer parameters

Nominal Power	SKVA/50HZ
Windings ($V_{1\,rms}$, $R_{1\,\Omega}$, $L_{1\,H}$)	500, 4.32, 0.458
Windings ($V_{1\,rms}$, $R_{1\,\Omega}$, $L_{1\,H}$)	250, 0.793, 0.084
Windings ($V_{1\,rms}$, $R_{1\,\Omega}$, $L_{1\,H}$)	250, 0.793, 0.084
Magnetization ($R_{m\,\Omega}$, $L_{m\,H}$)	$1.08 * 10^6$, 2866

5.1 PV generator model

The PV generators output power is calculated using measurements of ambient temperature (Ta) and sun irradiation (Ir). Several models for estimating PV-generating power can be found in the literature. This photovoltaic generator power is calculated using the model defined in the study [27]:

$$P_{PV} = \eta_r \cdot \eta_{Pc} \cdot [1 - \beta \cdot (T_c - NOCT)] \cdot A_{PV} \cdot I_r \quad (1)$$

$$T_c = 30 + 0 \cdot 0175 \cdot (I_r - 300) + 1 \cdot 14 \cdot (T_a - 25) \quad (2)$$

where:
T_a: Ambient temperature
I_r: Sun irradiation
P_{pv}: Photovoltaic array power
η_r: PV efficiency
η_{PC}: Power tracking equipment efficiency
$NOCT$: Normal operating PV cell temperature
T_C: PV cell temperature
$A_{p.v}$: PV panel area

5.2 Wind turbine model

The power of wind turbine is given by this equation:

$$P_{wT} = \frac{1}{2} \cdot C_{p.opt} \cdot \rho \cdot A_{wt} \cdot V_{wind}^3 \quad (3)$$

where:
P_{wT}: Wind Turbine Power
C_P: Power Coefficient
ρ: Mass Density
λ: Tip Speed Ratio
R: Radius of the Blade
A_{WT}: Cross Section Area
V_w: Wind Speed

6. FLOWCHART OF THE SUPPOSED SMART GRID

Figure 3 depicts the supposed flowchart of the studied smart grid where, the information referring data of hybrid solar PV-wind turbine system is arrived that will eventually permit the energy conversion equations. Three cases were considered in this procedure, ordinary plant with solar PV and wind turbine plants, ordinary with wind turbine plants. All of these cases were taken at periods of hours that suitable for each type.

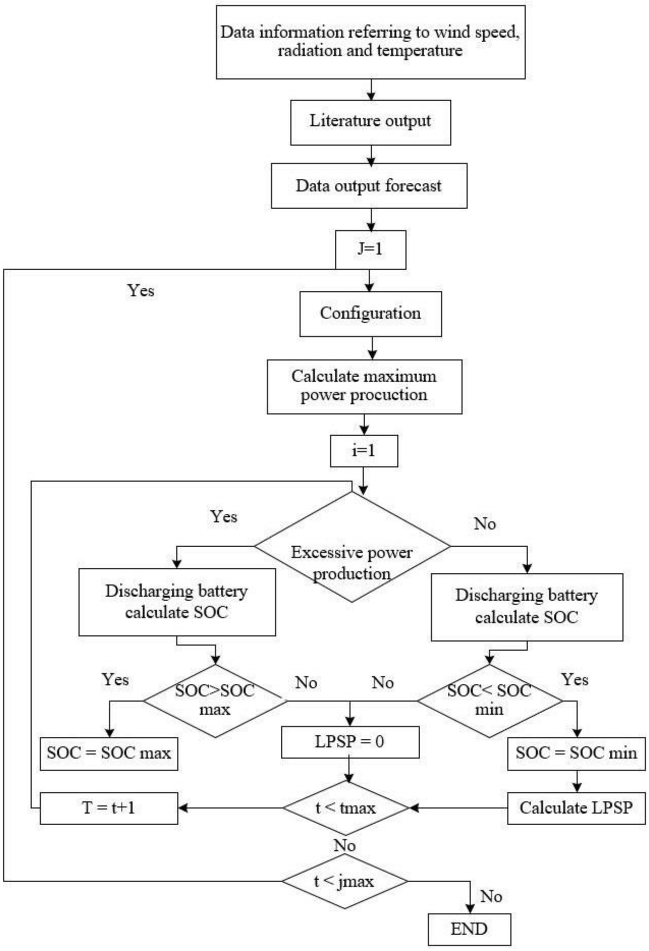

Figure 3. Flowchart of the process for suppling energy

7. RESULTS AND DISCUSSION

A simulation is done by deriving the equations of each plants, the system considered has three phase supply, three phase measurement, three phase power circuit breaker, maximum power demand, three winding power transformer (solar unit), solar loads, three winding power transformer (wind unit), wind loads and finally the total load, of the grid. A results validation is done.

A Matlab/Simulink is used for modeling the investigated system illustrated in Figure 4.

Figure 5 illustrates the behaviour of power with respect to time at load. From Figure 5 the behavior of power has no fluctuation at the beginning and stable at short period (short setting time).

Figure 6 illustrates the behavior of power with respect to time for solar PV plant (transformer of PV side). From Figure 6 the power value started from 9 O'clock time passed throw the maximum power point (MPP) at 24 O'clock and arrived to 73W at 24 O'clock and the power way continued after 17 o'clock this due to the energy storage inside the inductive load.

Figure 7 illustrated the demand of solar PV loads with respect to time. From Figure 7 the demeanor of power curve along the load in the PV side arrived to the MMP at 26W and reached to 17W at 24 O'clock and the power was continued after 17 O'clock this due to the energy storage inside the inductive load.

Figure 8 illustrates the behavior wind turbine plant (transformer side of wind turbine plant). From the figure the minimum power arrived 77W at 17 O'clock and reached to 83W at 24 O'clock.

Figure 9 illustrates the behavior of wind turbine loads with respect to time.

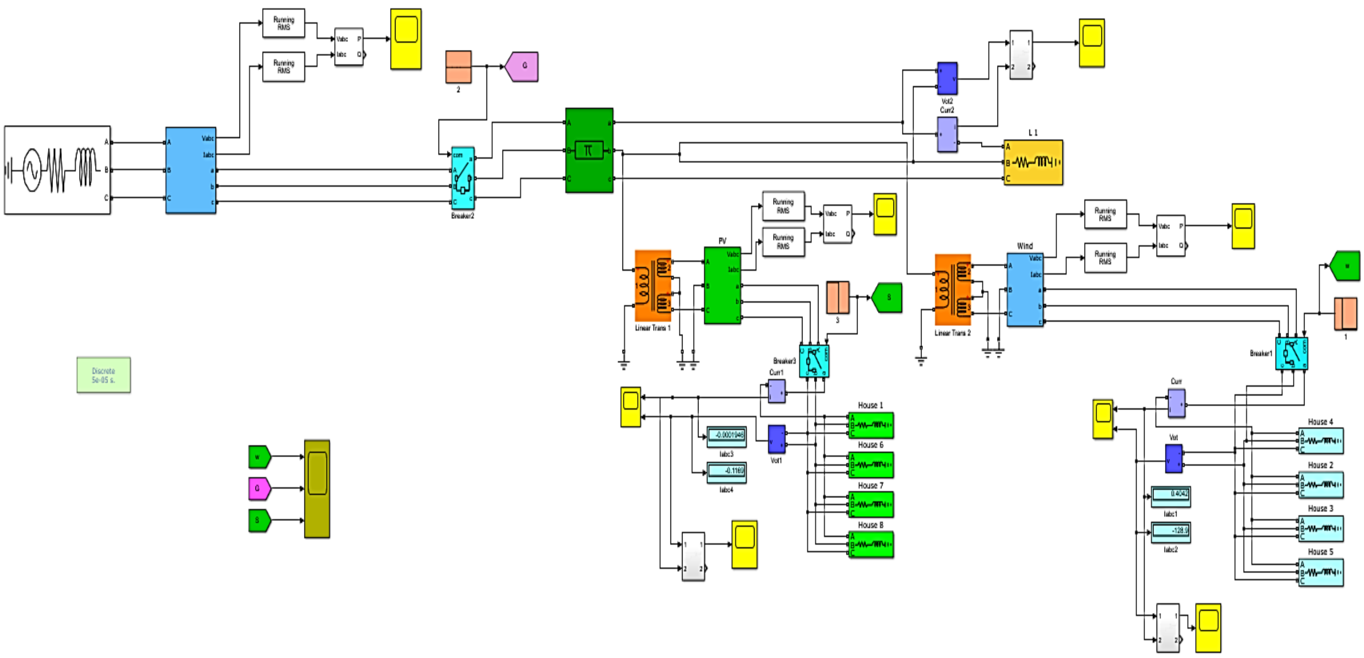

Figure 4. Simulation circuit implemented by Matlab/Simulink

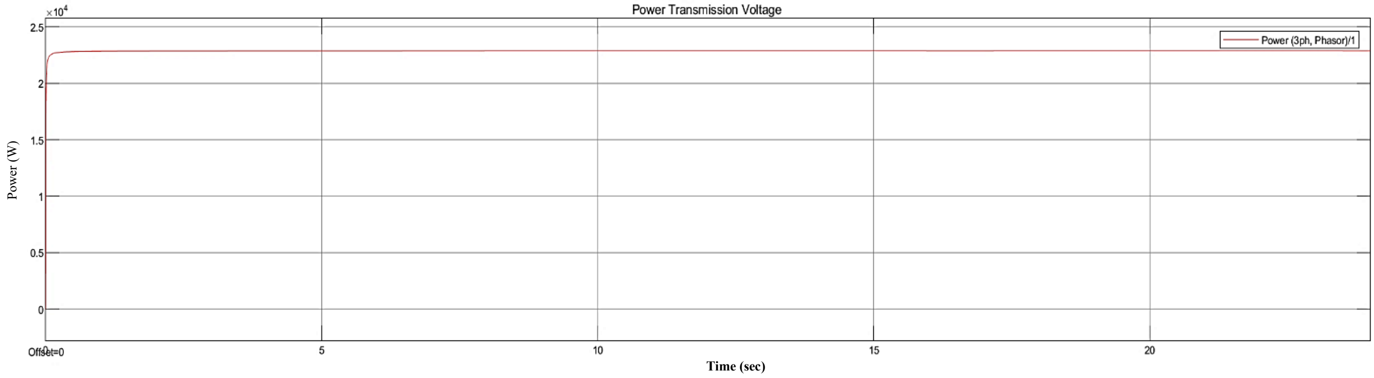

Figure 5. Power Vs time at load with existance of ordinary and wind turbine energy

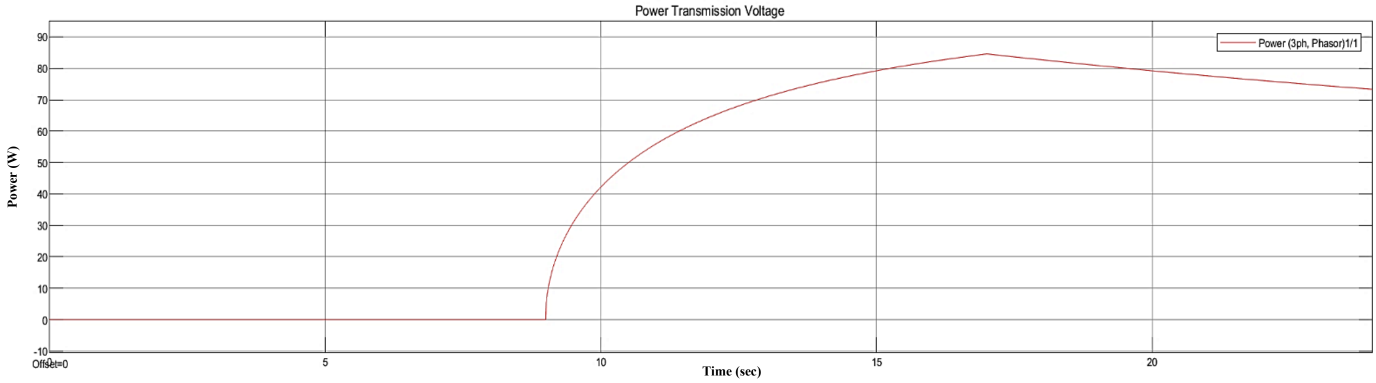

Figure 6. Solar PV (transformer power) vs time with existance of ordinary and wind turbine energy

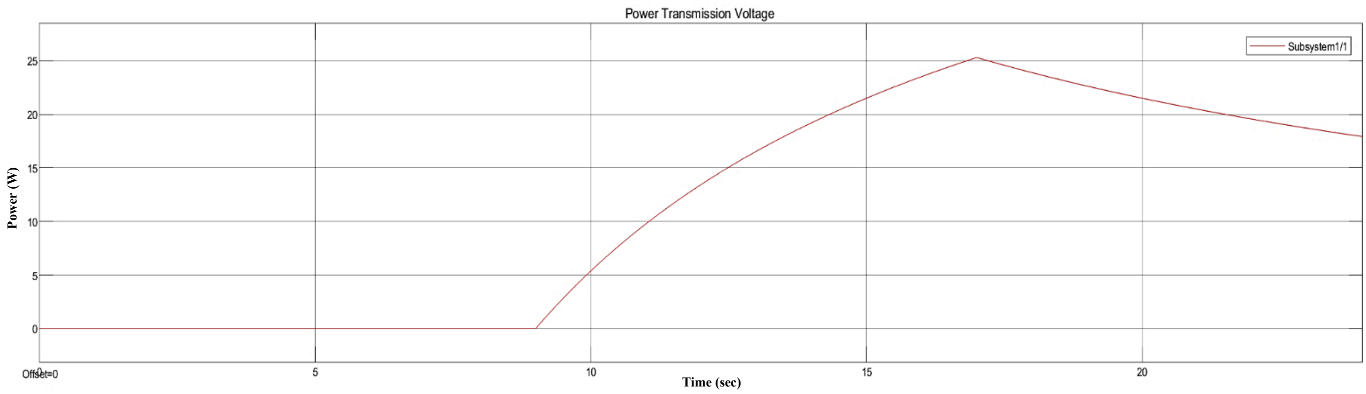

Figure 7. Demand load power vs time supported with solar PV plant with existance of ordinary and wind turbine energy

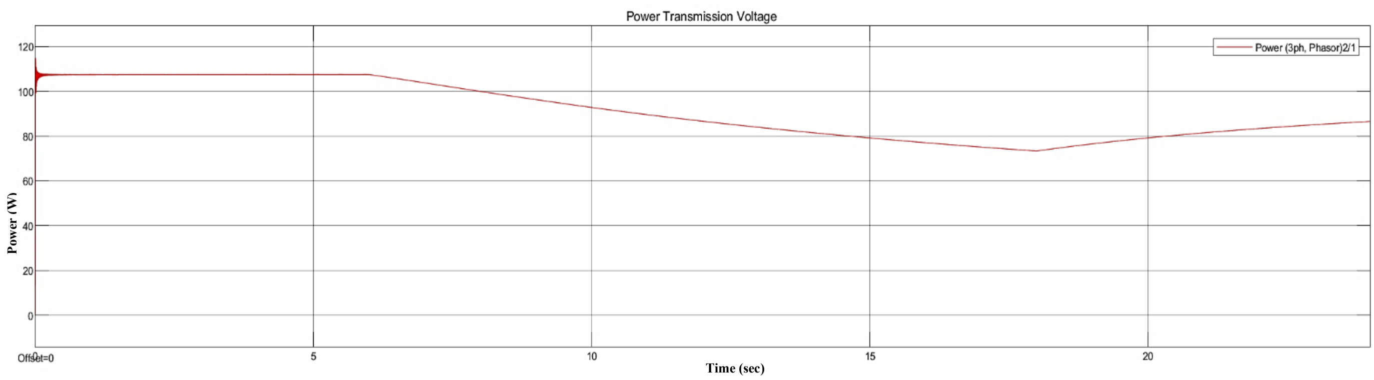

Figure 8. Wind turnine (transformer power) vs time with existance of ordinary and solar PV energy

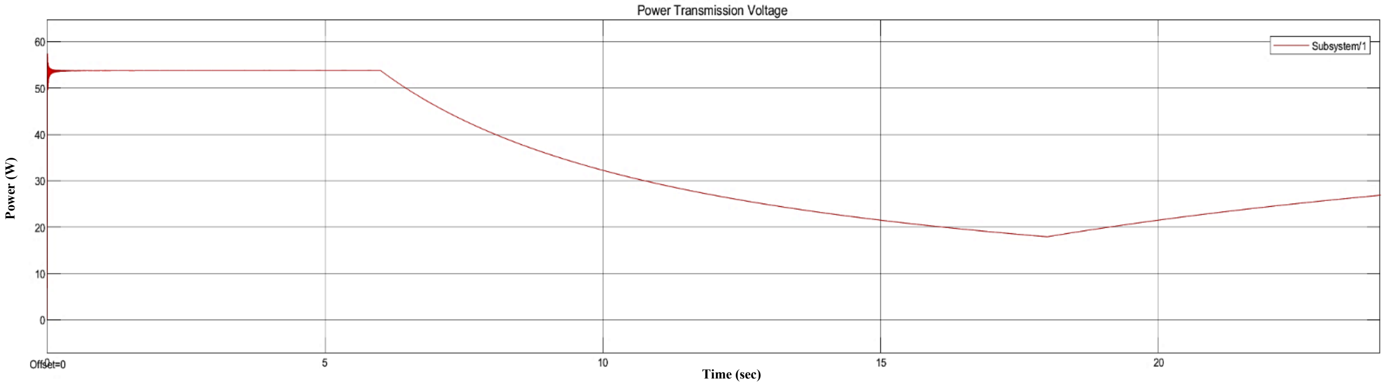

Figure 9. Wind turnine load power vs time with existance of ordinary and solar PV energy

Figure 10. Demand load power vs time supported with wind turbine plant with existance of ordinary and solar PV energy

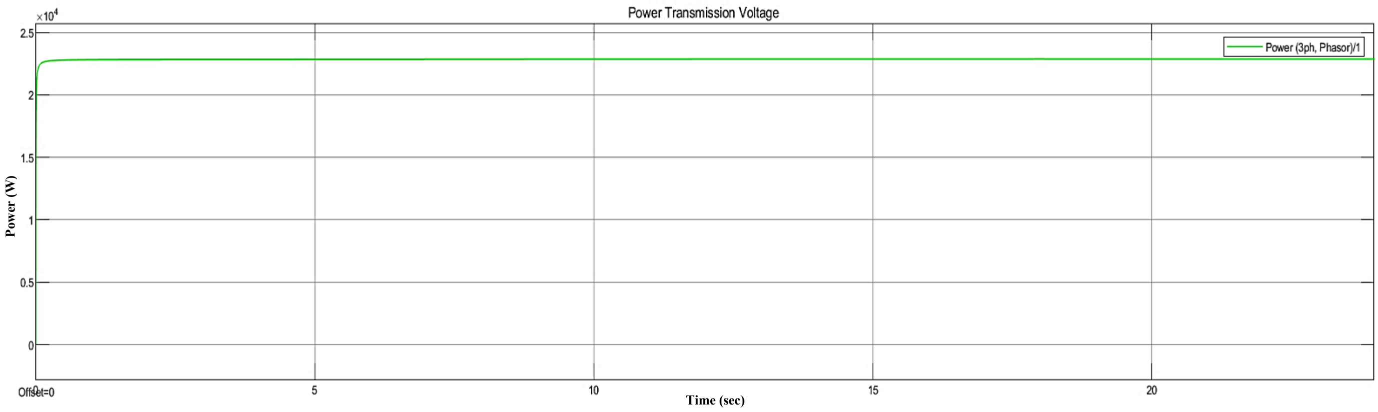

Figure 11. Demand source power vs time

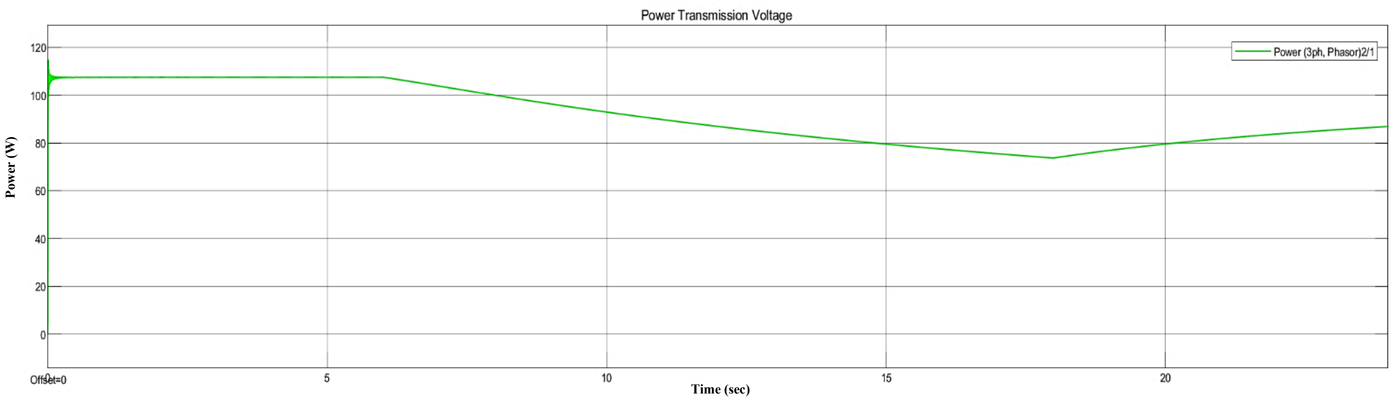

Figure 12. Wind turbine (transformer side) power vs time at absence of solar PV plant

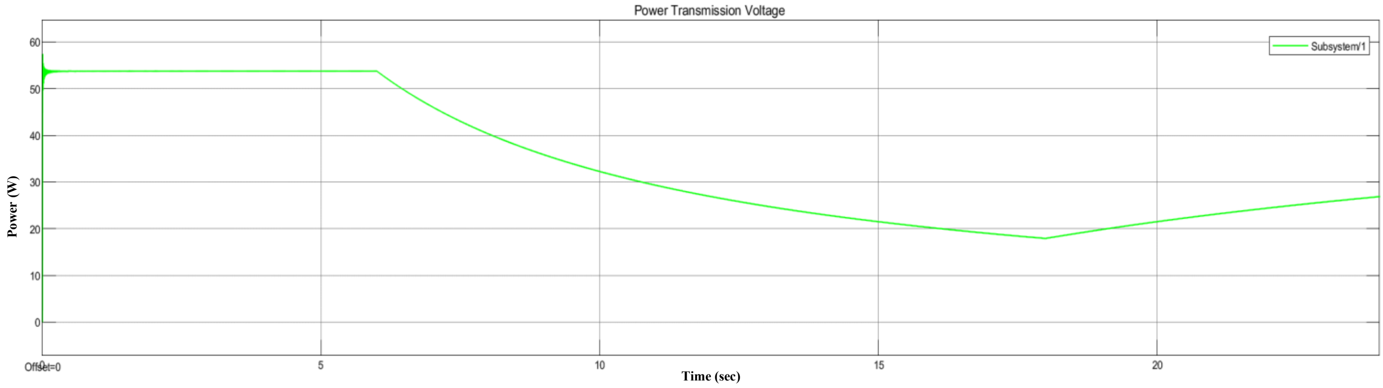

Figure 13. Wind turbine load power side vs time at absence of solar PV plant

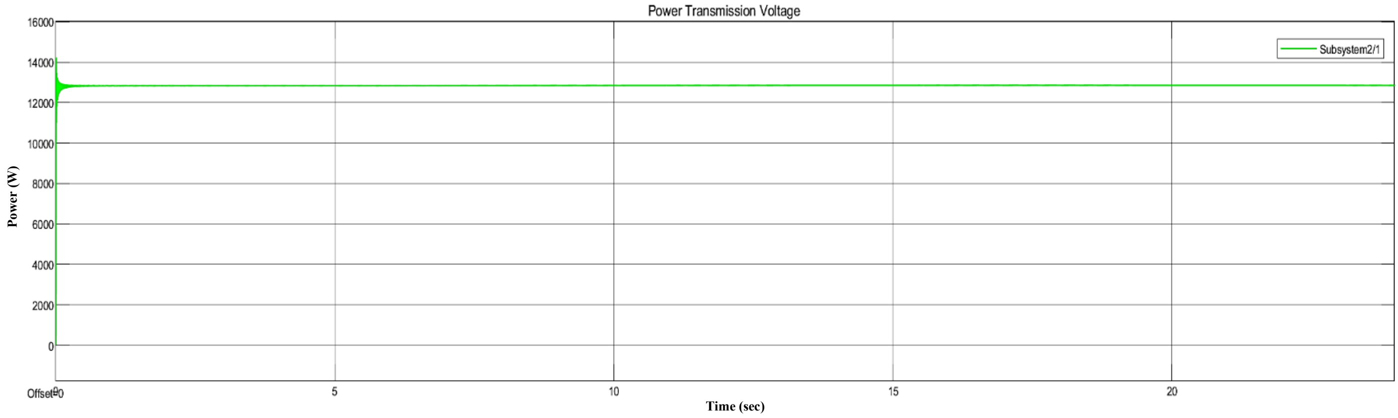

Figure 14. Total grid load power vs time

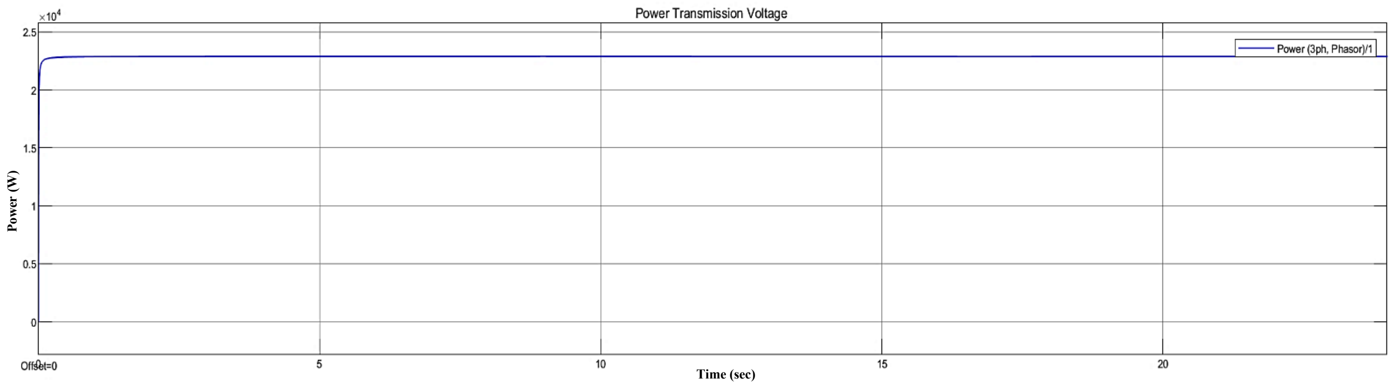

Figure 15. Source power vs time at absence of wind turbine

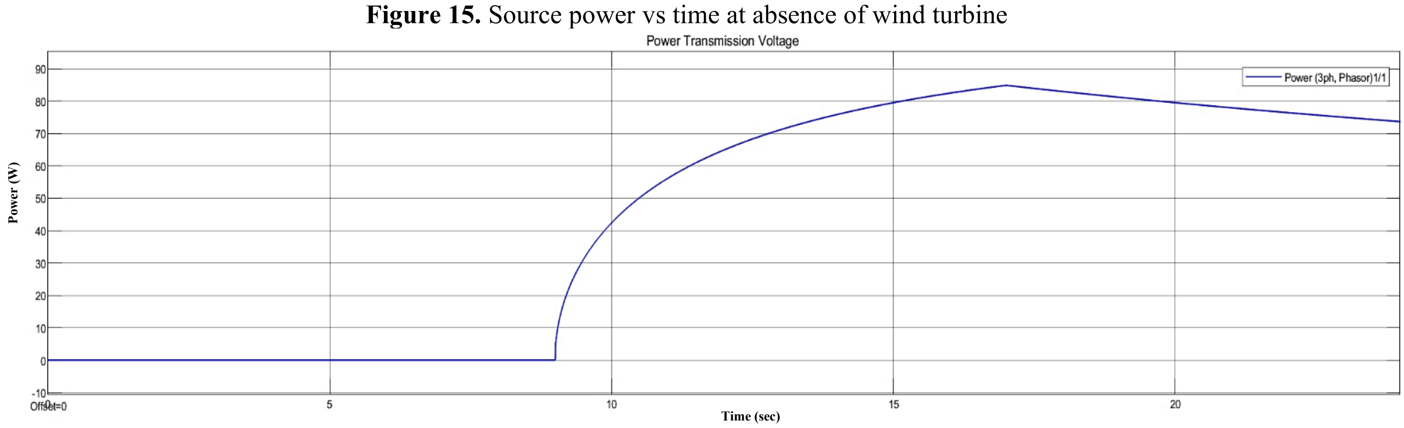

Figure 16. Solar PV (transformer side) power vs time at absence of wind turbine

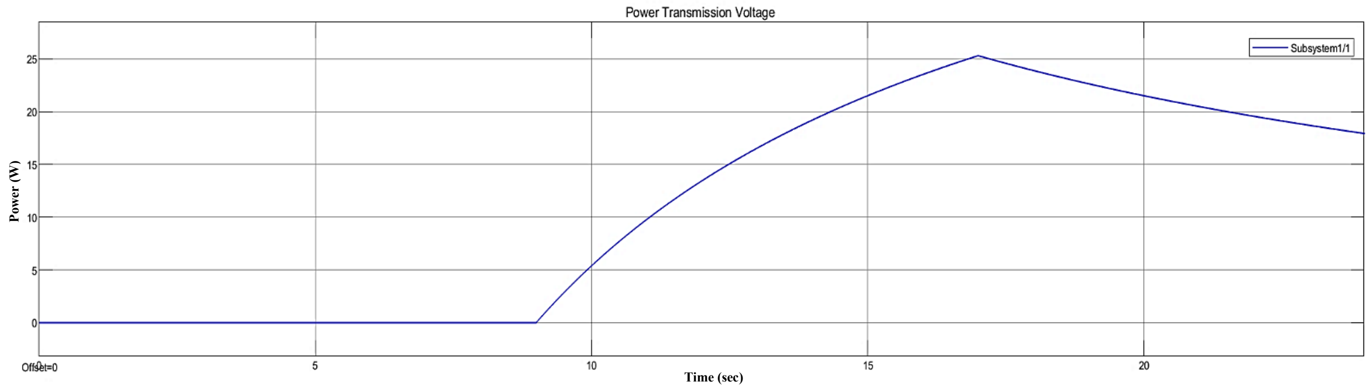

Figure 17. Power load demand of solar PV at absebce of wind turbine plant

From the figure the behavior of power curve along the load in the wind turbine side arrived to minimum power point 18W at 17 O'clock and reached to 36.5W at 24 O'clock.

Figure 10 illustrates the demand of load power with respect to time.

Figure 11 illustrates the demand of source power with respect to time.

Figure 12 illustrates the behavior of wind turbine power (transformer side of wind turbine) with respect to time with absence PV plant.

Figure 13 represents the behavior of wind turbines loads with respect to time at absence of PV plant.

Figure 14 represents the demeaned of power curve with respect to time at total load of the grid.

Figures 9-14 show that the wind turbine supply enables to fed the owns loads individually as same with finding the coupling connection point linked with ordinary three phase power source.

Figure 15 illustrates the behavior of source power curve with respect to time.

Figure 16 illustrates the power curve with respect to time of solar PV plant (transformer side/solar plant) at absence of wind turbine plant.

Figure 17 illustrates the wind turbine loads with respect to time.

From Figures 15-17, the results showed that the solar PV supply enable to fed the owns loads individually as same as with finding the coupling connection point linked with ordinary three phase power source.

8. CONCLUSIONS

In this paper, designs and models a unique solar PV and wind turbine hybrid system to be used in the applications of the smart grid. The algorithm created consists of system elements and a suitable power flow controller. The PV systems obtainable electricity is greatly relied on solar radiation. To address this shortcoming of the PV system, the PV unit was integrated with the wind turbine, which had the ability to supply the whole load at peak load as well as the external load independently. The solar photovoltaic and wind turbine energy were enabled to support the ordinary grid at peak load periods.

Modeling system illustrates the behavior of load power with respect to time at the beginning and short settling time and no power fluctuation, the power increased with increase the time and the result showed that the wind turbine, solar PV supply enables to feed the own load individually as same with finding the complying connection point linked with ordinary phase power source.

The proposed work was compared with another one paper titled as "Modelling and simulated for smart grid integration of solar/wind energy", the behavior of the system and the curves shapes appeared similar to that work as mentioned in above title but at peak load period, they depended on the generator to compensate the deficiency but at out-off sunlight and wind blowing period but here the total load and individual loads programmed depending on the duration of presence the sunlight and wind blowing.

This smart grid can be implemented practically as a further work at any site in Mosul city.

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