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Integration of Hybrid Grids in Smart Grid

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Abstract: The subject of study is the integration of a Hybrid grid in a traditional grid by using wind-connected AC-DC converters or DC-AC inverters and PV maximum power extraction using the MPPT method. As the grid used for our power system is the old century grid and works with fossil fuels for electricity generation. To overcome the problems created by fossil fuels use of RES or Hybrid Grid is suggested. The power generated from RE sources can be enough for an island or a small area but big areas or grid-level integration of HRES with traditional grids is needed. But it's not quite simple because the outputs are not the same, unregulated and when connect with local grids produce fluctuations, frequency differences, and many more faults. A control network is proposed in this thesis. The whole conversion system is consisting of wind-connected AC-DC converters and IGBT's controlled DC-AC inverter and PV maximum power extraction system using MPPT with Battery storage. At last combined Matlab simulation of HG consisting of PV and Wind as a subsystem with results is given. The major difference of this research from the literature is the use of multiple renewable sources in power systems and their integration with large-scale power grids.
Keywords: HG (Hybrid Grid), MPPT, PV, RES

1. Introduction

Power Systems (CPSs) were designed in the 1950s and built in the 1960s and 1970s. So this is the reason they are becoming old and consequently becoming unable to work with new applications such as integrating distributed energy resources (DERs) including renewable energy sources (RES) and Storage systems into electrical networks. It is important to mention that the conventional grid, the electrical grid of the old century, is a one-direction network. This means that electricity flows in one direction from generating stations to substations, by using transmissions lines to the consumer end or load. The energy grid is a complicated and vital system that is also one of the most spectacular engineering marvels of our time. It transfers the power generated at a variety of facilities, typically across vast distances, to end customers [1].Plants and animals decompose to produce fossil fuels. These fuels, which can be found in the Earth's crust and contain carbon and hydrogen, can be burned to generate energy. Fossil fuels include coal, oil, and natural gas. According to scientific research, there is a prediction that if we continue to use fossil fuels at the current rate then fossil fuels will be depleted in 2060 [2]. So we should have shifted to an alternative way to produce electrical energy which is more economical, environment friendly and renewable.

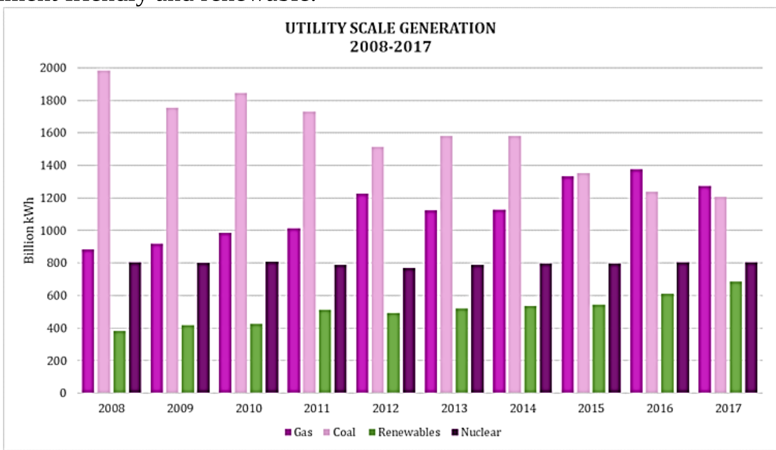

Figure 1 Generation w.r.t Sources

According to a research byIEA (2018), "World energy balances", *IEA World Energy Statistics and Balances* 37.9% percent of the total electricity of Turkey is produced from Natural gas whereas 29.1% is from coal and coal products which combined is 67 percent of the total electricity generation of Turkey [3]. In 2020 total electric energy produced by turkey was 272.03 TWh of which approximately 178 TWH energy was produced by natural gas, coal products, and oil products. This means that turkey or world electricity generation is highly dependent on these non-renewable energy sources known as fossil fuels [4].

Energy obtained from renewable resources is frequently referred to as "renewable energy" or "clean energy." While these two names are frequently used interchangeably, it's vital to know the differences between them because each relates to a somewhat different form of energy. Renewable energy is energy derived from renewable resources that refill over time and do not deplete. Renewable energy comes in a variety of forms, and its proportion in the generation mix has shifted throughout time. With 44 percent of total renewable energy in 2017, hydroelectric remains the largest producer, however, wind power has had the most significant increase, accounting for 37 percent in 2017. Solar comes in second with 11% and geothermal comes in third with 2% [5]. All these RE sources can be enough for a small island or small area but for larger areas and cities the need for fossil fuels is also required. So a network is required which consists of both RE sources and fossil fuels to overcome the demand as well as using most of RE sources.

2. Hybrid Grid

A hybrid renewable energy system is essentially an energy generation facility that combines two or more independent renewable technologies.

Everyday renewables become a bigger part of our Energy System. Today Renewables account for more than 22% of the electricity generated around the world and are expected to reach 26% by the year 2020. But the wind doesn't always blow and the sun does not always shine when you need it. This is why energy storage and other technologies are developed to expand the grid capacity. Of course, there are certain industry standards for individual storage systems. For cells, modules, battery management systems, and Energy management systems. But until recently no power system control the energy storage system as well as the demand of each component and then connects these separate components effectively to the local grid.

The three main types of hybrid renewable plants observed in the global market:

- Solar and wind hybrid
- Wind with energy storage, and Diesel Generator
- Solar, wind, and energy storage hybrids

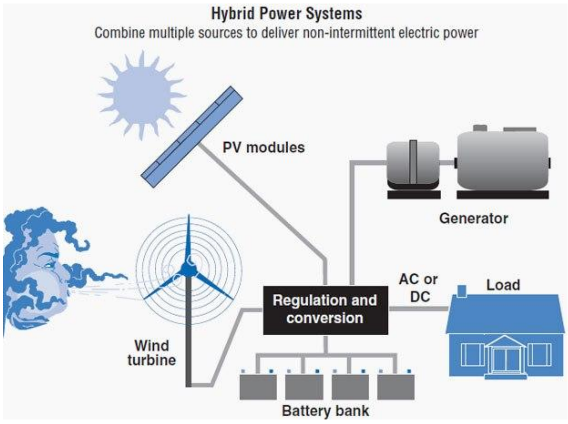

Figure 2 Hybrid Grid and its Components

Hybrid plants offer many advantages against traditional and single solar panel plants and wind farms.

The comparison between traditional and hybrid renewable power plants is highly dependent on these three main parameters listed below:

- Cost of productivity
- Availability of the System
- Flexibility in operations

PV system integration or mixing into a hybrid system's generating blend offers several technical and nontechnical issues. The most significant nontechnical problems in integrating PV systems are primarily related to system planning and design, operation, and maintenance, which are all fundamentally localized issues that vary from site to location. Voltage and frequency fluctuation, harmonics, voltage flickering, and imbalance, switching off electrical equipment, system blackouts, islanding detection, electromagnetic interference, and other technical concerns are all recognized globally [6]

3. METHODS

3.1. Grid Interconnection

HRESs are defined as (a) one RES and one or more ES; (b) two or more RESs (with or without ES); or (c) one or more RESs plus one or more non-renewable energy sources (with or without ES) [9]. However, runoff, sun irradiation, wind speed, and ambient temperature all have an impact on the power generating properties of these sources. As a result, a combination of multiple energy sources can efficiently overcome the challenges of solar/wind energy's randomness, variability, and unpredictability. Previous research has focused on small-scale off-grid hybrid systems that primarily use solar and wind energy sources for small-scale generation and most of them are using a single source at a time. So in this article, the wind-solar Integration with ES is been discussed [7].

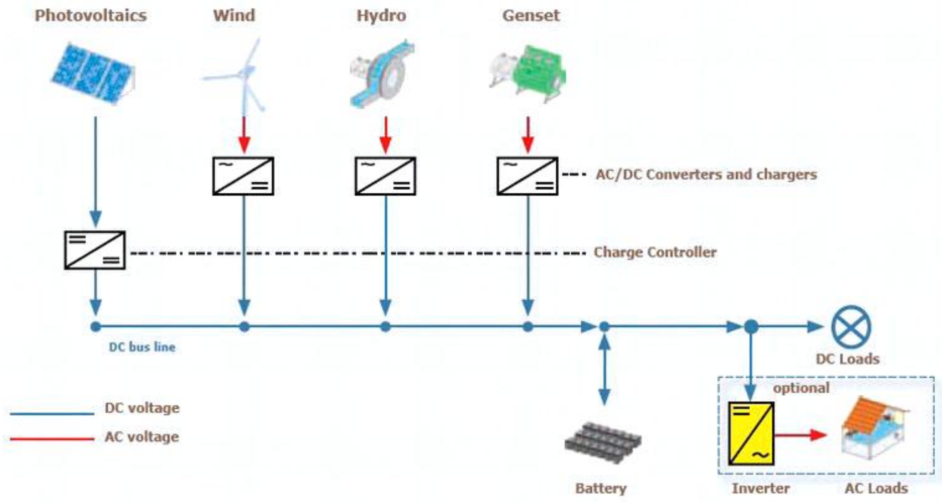

Figure 3 Energy Flow Diagram

3.2. Integration of PV, Wind, and ES

From the block diagram, it can be seen that the output of the PV module is DC voltages, whereas the output of the wind and Diesel generators is the same AC. Regarding the same output of wind turbine and Generator, we cannot connect them directly to the grid because of various reasons discussed above. So a reliable interface is required because that a bus is used with whom the output of PV can be connected. The output of DC is further passed from the DC-DC MPPT converter with battery storage because the output of PV is irregular and unstable. So to control the PV output DC-DC MPPT with battery storage is used. The output of the Wind turbine-connected synchronous generator is converted through AC- DC converter and then all the DC outputs are transferred to the DC bus [8].

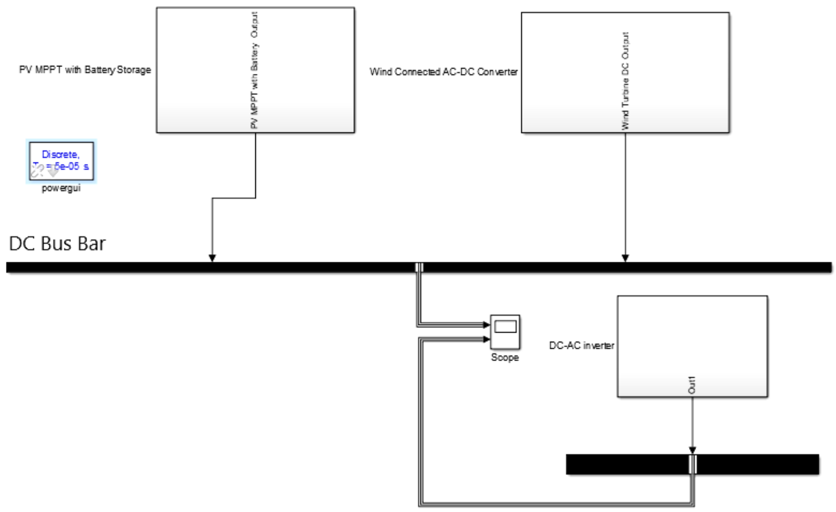

Figure 4 HG system consists of PV and Wind as a subsystem

4. MATLAB SIMULATIONS AND RESULTS

4.1. PV CONNECTED MPPT WITH BATTERY STORAGE DESIGN PARAMETERS

P = 210W
Vin = 28-36V
Output 11.5~12V
Fsw = 5Khz
Iripple = 10%
Vripple = 1%
Io = Rated Power / Input Voltages
Output Current = 210/12 => 17.5A
Current ripple is 10% of 17.5 = 1.75A
Voltage ripple is 1% of 12 = 0.12V

$$Inductance, l = \frac{Vop\ (Vip - Vop)}{fsw * Iripple * Vip} \quad (1)$$

$$Inductance, l = \frac{12\ (28 - 12)}{5000 * 1.75 * 28}$$

$$Inductance, L1 = 0.783\ mH$$

$$Capacitance, C1 = \frac{Iripple}{s * fsw * Vripple} \quad (2)$$

$$Capacitance, C1 = \frac{1.75}{8 * 5000 * 0.12}$$

$$Capacitance, C1 = 364 * 10^{-6}\ Farad$$

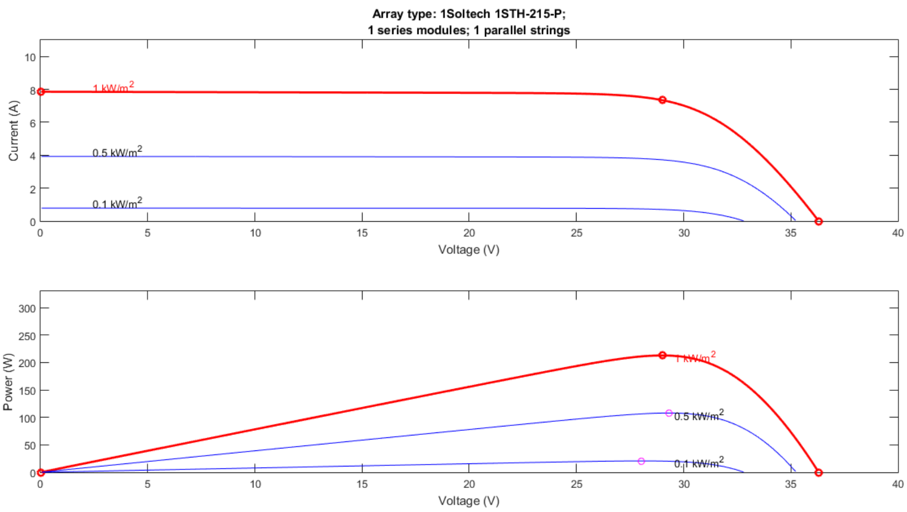

Figure 5 PV Maximum PowerPoint

The above graph shows the maximum power point of the used PV module of 215W power at the voltage of 28 Volt and irradiance of 1000 W/m2. The above graph shows the value of maximum current at the 28 voltage and 1000 W/m2 irradiance. And the 500 and 100 irradiances the current is decreasing accordingly. And the below graph shows the maximum value of power at 28V and irradiance of 1000, whereas changing the irradiance to 500 or 100 changes the value of power to the downside.

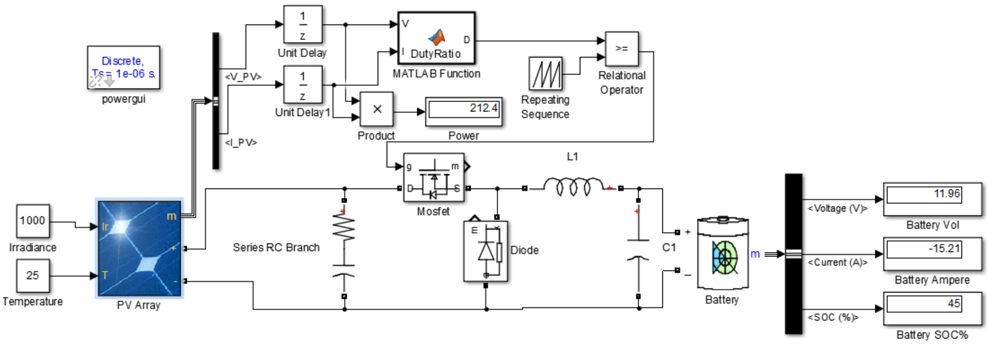

Figure 6 PV connected MPPT with Battery Storage

In the above simulation, we used the design parameters that are calculated above
P = 210W, C = 364μf and L = 0.783mH from calculations

In the above Matlab simulation, the Lead Acid battery is used with a 100 A/H rating. A series RC branch is connected with the parallel of the output of PV which is further connected to the Drain of the Mosfet and the Anode of the Diode. A series inductor of the above-calculated value and capacitor of 364 microfarads is attached with the diode. The lead-acid battery of 12-volt output and 100A/H rating and 45% SOP (State of Charge) is attached parallel to the capacitor. The output of the battery is further sent to a bus selector which is displaying the results of Voltage current and SOP percentage of the battery. The measurement port of the PV module is connected with a bus selector with the value of Vp and Ip. The output of the Bus selector further passed from two-unit delay functions of sample time 1e^-4s and sent to the product function to output the given power of PV. And also the output of the Unit delay functions is passed from the Duty Ratio function to output Duty Ratio D by passing from the Rational operator greater and equal to the Drain port of Mosfet. It can be seen that at 1000 irradiance the output power of PV is 212.4 and the Battery current is 15 whereas battery voltages are 11.9.

Table 1 Power, Voltage and Current at different input irradiances

Serial #	Irradiance in W/m^2	PV Power (P_{rated}) in Watt	Battery Voltages	Battery Current in Amp	SOC (State of Charge)
1.	1000	212.4	11.9 V	15.21 A	45%
2.	500	108	11.9 V	7.4 A	45%
3.	100	20.57	11.9 V	0.7 A	45%

It can be seen that after changing the irradiance from 1000 to 500 the rated power of PV is reduced from 212 to 108 and the current of the battery is reduced from 15 A to 7.4A. The Results of rated power, Battery Voltages, and Current at different radiances such as 1000, 500, and 100 W/m^2 are mentioned in the above table.

4.2. Wind Connected AC-DC converter

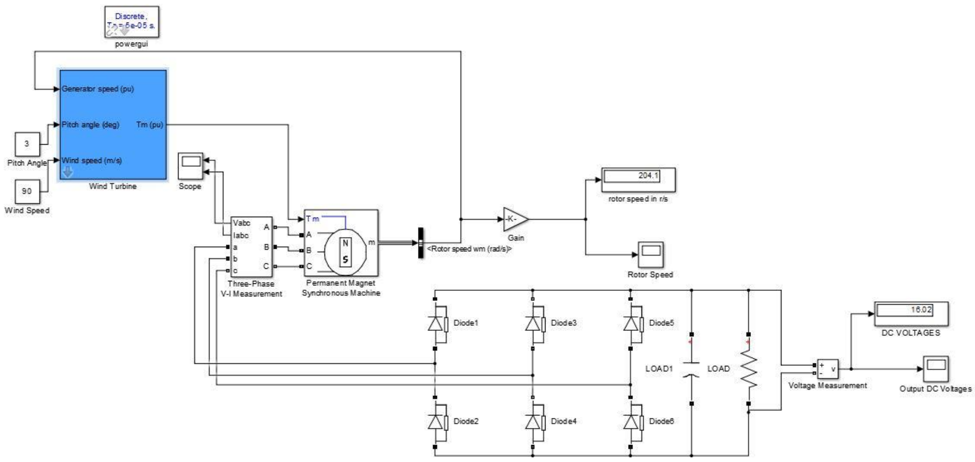

Figure 7 Wind Connected AC-DC Converter

$$\frac{di1}{dt} = -\frac{r}{L}i1 + \frac{1}{3L}(2Ug1 - Ug2 - Ug3) - \frac{Uo}{6l}(2U1 - U2 - U3) \qquad (3)$$
$$\frac{di1}{dt} = -\frac{r}{L}i2 + \frac{1}{3L}(2Ug2 - Ug1 - Ug3) - \frac{Uo}{6l}(2U2 - U1 - U3) \qquad (4)$$
$$\frac{di1}{dt} = -\frac{r}{L}i3 + \frac{1}{3L}(2Ug3 - Ug1 - Ug2) - \frac{Uo}{6l}(2U3 - U1 - U2) \qquad (5)$$
$$\frac{dVo}{dt} = -\frac{Uo}{RC} + \frac{1}{2C}(i1U1 + i2U2 + i3U3) \qquad (6)$$

There are three main structural parts in the circuit shown in figure 7. Synchronous generator, Full bridge circuit consists of six diodes as switches and RC-type output filter. The output of the synchronous generator passed from the three-phase full-bridge AC-DC converter by using six diodes with Resistance R of 10 ohms as load. The capacitor C is attached in parallel with Load R to reduce the harmonics. The Wind turbine with the speed of 90 m/s and the pitch angle of 3 is shown in the above figure. The generator speed-up point is attached with the rotor Tm of the permanent magnet synchronous machine. And the output which is consists of three-phase AC and voltages which are being measured by Three Phase V-I measurement and shown in the below figure with red, blue, and green colors as i1Ug1, i2Ug2, and i3Ug3 [10].

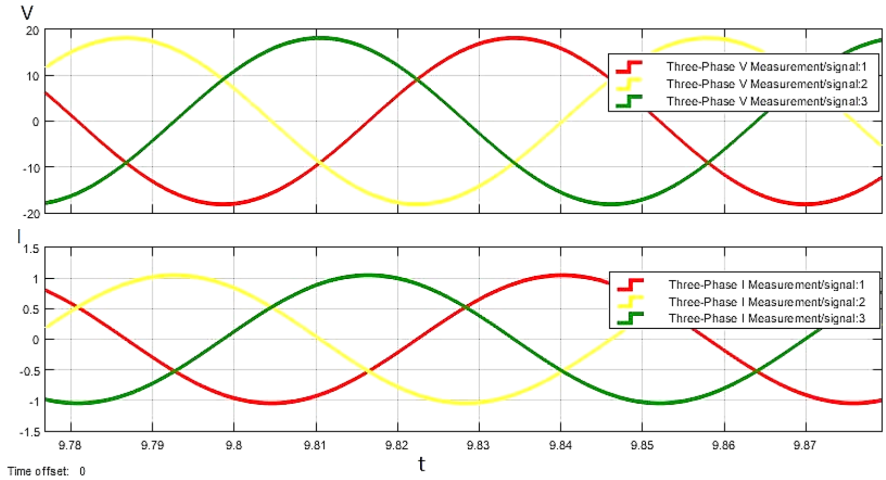

Figure 8 Three Phase Synchronous Generator Output

DC Output

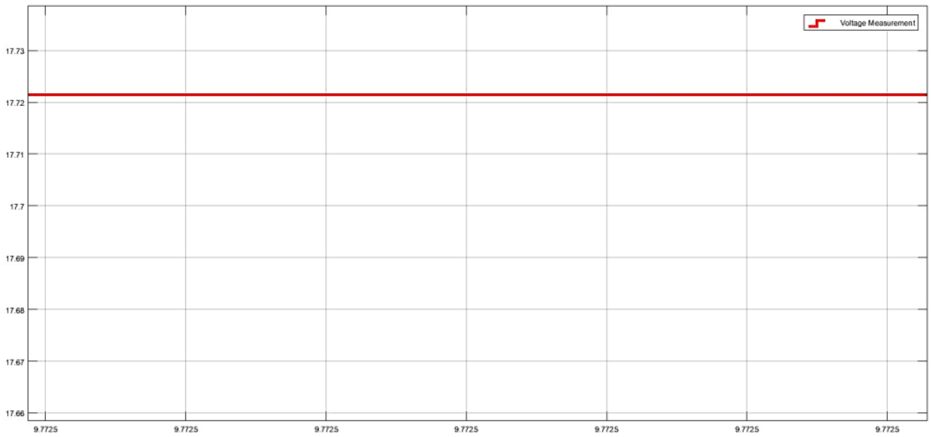

Figure 9 Wind turbine connected AC-DC converter output DC voltages

4.3. Full bridge DC-AC inverter

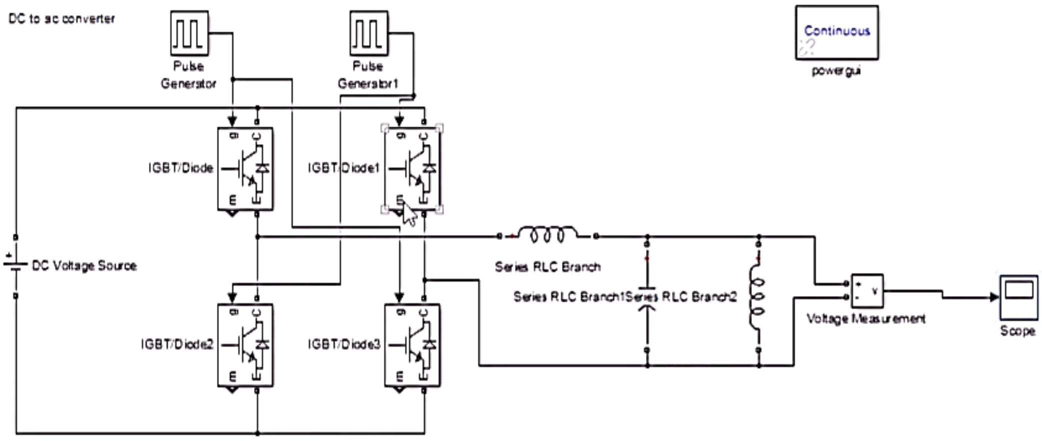

Figure 10 Hybrid DC-AC Inverter

For power electronics IGBT (Insulated Gate, Bipolar, Transistor) are used. IGBTs are Mosfet which stands for Metal Oxide Semiconductor field-effect transistors. We can use these MOSFETs the same as a diode for switching purposes. IGBT consists of three pins named collector, emitter, and gate which are represented in the diagram by c, e, and g. The main reason for using IGBT is because of their high voltage and current ratings. In figure 35 a Matlab simulation for Inverter by using IGBT's is shown. The DC input supply taken here is 12 volts. The period used is T1/2000. The collector of IGBT 1 is connected with the emitter of IGBT4. Whereas the Collector of IGBT2 and IGBT4 and Emitter of IGBT1 and IGBT3 are connected. The gate of IGBT and IGBT3 is connected with Pulse Generator. The Gate of IGBT2 and IGBT1 is connected with logical NOT operator output. So IGBT and IGBT3 work together for one cycle of pulse and after NOT logical operator the other two IGBTs turn ON and pass the other cycle.

Result

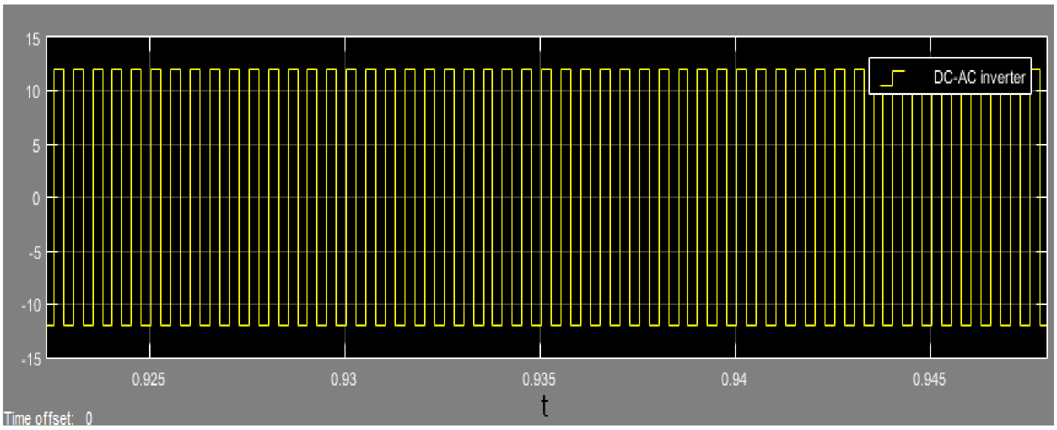

Figure 11 Inverter output

5. CONCLUSION

The subject of this research is the method by which Hybrid Grid integrations are possible to reduce the overall share of fossil fuel in energy production without any problem and change to existing grid infrastructure with the help of AC/DC or DC/AC converters and maximum power extracting system for PV with battery storage. In the literature review, most research is about using PV or wind energy as single sources. Or the research is about only smart grids which include the importance of smart grids, advantages, and disadvantages of smart grids, sizing of smart grids, or microgrids or microgrids which are suitable for only small scale generation. Also, the previous data used in literature about the usage of fuels by year, or total energy production by year is old and obsolete. Whereas in this thesis the data mentioned such as tables and graphs are not very old, which provide better analytics and an overview of current situations. Also, the limitations of traditional grids, the disadvantages of fossil fuels, advantages of RE sources are explained in this article. RE sources used as a single source are insufficient to meet the energy needs of the modern era. So in this scenario using multiple energy sources can overcome the energy requirements. The wind turbine connected AC to DC full-bridge converter Matlab simulation and its results are stated. Also, the maximum power point extraction using PV as a source with battery storage simulations has been done and the results according to different input conditions are mentioned. At last, the combined Matlab simulation of a Hybrid System consisting of PV and Wind as subsystems is shown with results. In table 2 difference between the three energy systems is given and can be seen that the HG can have a high initial cost but in the long term it offers more flexibility, cost-effective, and environment-friendly green energy.

Table 2 Different Energy Systems Comparison

	Conventional Grid	**Micro Grid**	**Hybrid Grid**
1.	Electromechanical infrastructure	Digital infrastructure	Digital infrastructure
2.	Unidirectional Energy flow	Bidirectional Energy Flow	Bidirectional Energy Flow
3.	No support for Distributed Generation	Small scale Distributed Generation	Large scale Distributed Generation
4.	Low installation cost	Medium installation cost	High installation cost
5.	Low maintenance cost	Medium maintenance cost	High maintenance cost
6.	Large scale generation Long transmission lines	Smaller-scale generation No transmission lines	Large scale Generation Long Transmission lines
7.	Manual Monitoring	Self-Monitoring	Self-Monitoring
8.	Manual Restoration	Self-healing	Self-healing

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