Performance Analysis of Solar/Wind Nanogrid for Rural Electrification in Offgrid Mode

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Abstract — In last two decades, the application and research orientation towards utilization of distributed generation systems is at its peak. Electricity generation and its usage coordination are vital aspects of energy efficiency that can help in saving energy, decreasing energy costs, and fulfilling global emission objectives. In this context nanogrid structure renewable energy utilization has emerged as a boon. Nanogrid is a small power entity which can be installed near load centre dedicatedly for small and mini applications like house hold or far a building usage using Alternative Energy Sources like solar/wind. This paper investigates the concept and architecture of nanogrid structure. It utilization, component requirement and topological survey is also presented.

Keywords: Alternative Energy Sources (AES), Nanogrid, Dc-nanogrid (DCN), Ac-nanogrid (ACN), Solid State Technology (SST).

I. INTRODUCTION

Energy crisis and environment protection against carbon emission has forced towards the utilization of Renewable Resources (RR) for power generation. RR are green sources of energy which are ecofriendly and also abundantly available like solar, wind, fuel cell, etc [1]. The power produced via RR are DC in nature and series of conversion stages are required to make it in parity to the utility characteristics. The process of conversion is costly as well as not much economical due to the requirement of high power converters. This problem has proved to be a boon in developing the microgrid and nanogrid system [2]. The concept of microgrid is to energize the local demand via RR by utilizing the generated power near load centres without developing long route transmission [3, 4]. The microgrid energizes an area comprising of small community, schools, hospitals, commercial buildings and is designed by integrating different Distributed generation. This then leads to a controllable, flexible power subsystem that can connect or disconnect from the main power grid [5]. The microgrid concept is further retrenched to “nanogrid” where generation is utilized for a house or small building. The concept of nanogrid is new and not more research work is available [6, 7]. But still the researchers are trying to implement it as much as possible since it is very user friendly and can be implemented by the customer to meet its day to-day demand.

The conceptual structure of nanogrid is shown in figure 1, which is designed using local power production like rooftop solar/wind, local loads, a gateway which is a bidirectional converter interfacing used for the purpose of power conversion as well as serves as a medium for linking other nanogrids, microgrids and with the utility grid [8, 9].

In this paper solar and wind two RR are integrated to form a nanogrid in a way to energies a remotely located area in standalone mode. In remote areas electricity access is either not feasible or very costly since transmission losses are high. Concept of nanogrid is highly appraisable for such applications to provide electricity where there is no hope for the same.

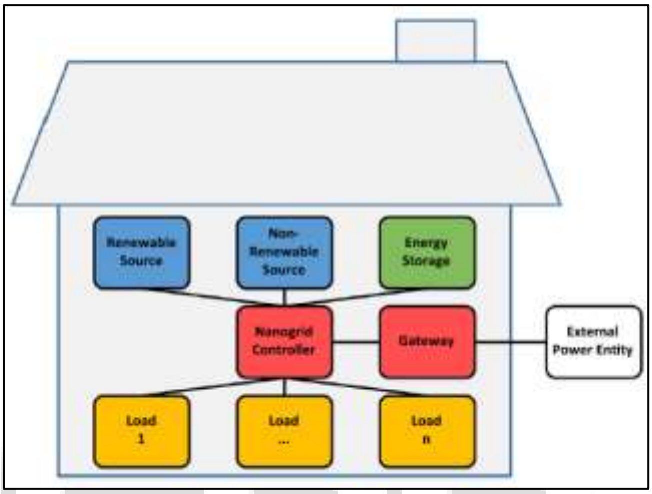

Fig. 1: Concept grid connected Nano grid system

II. PROPOSED WORK

In this paper a nanogrid is designed using solar and wind hybrid power generation system. The nanogrid designed is a low power grid of the rating of below 10KW, which serves the purpose of residential building in standalone mode.

The size of the nanogrid can be flexible as per the demand. Its design range is very flexible which is ranging for an inhouse application to several kilo watts feeding a village in islanded mode [10, 11]. Solar photovoltaic (SPV) and wind power generation system (WPGS) are the most practical and expanding power generation technologies which is globally accepted among all Sustainable Power Sources (SPS) for electricity generation. Analysis of the SPV and WPGS interface is the primary goal of the work presented in order to restore grid characteristics. The key challenges of using these SPS are generator selection, integrated system structure, and control calculations [12]. It is simple to locate a wealth of information to develop strategies like how to maintain planned electricity from the SPS [13]. These combine various generator topologies, power converter topologies, and control strategies to supply the load based on the voltage and harmonic content of the source. The researchers are working on a variety of solutions for combining various types of SPS and their operational perceptions in grid-connected and off-grid modes [14, 15].

Figure 2 presents a typical hybrid renewables sources of energy [16]. The source of energy are wind and PV in the proposed integrated system. They are interfaced to the DC bus that could be connected to a different energy storage system, or inject the current directly with a DC/AC inverter. Therefore, the characteristic of energy storage for a PV system will be explained as well as some specification and standards for a grid connected PV system.

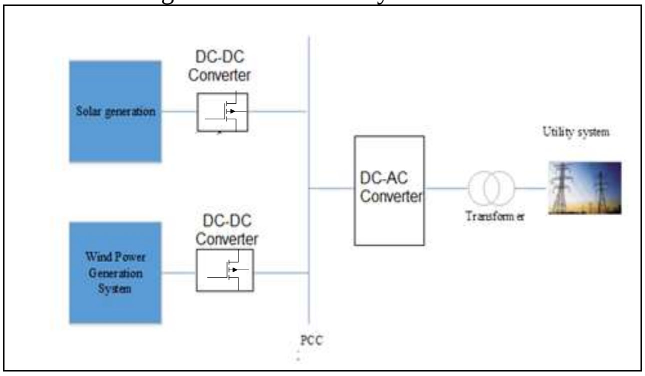

Fig. 2: Schematic of the proposed nanogrid system

III. GENERATION OF SOLAR POWER (GSP)

A Solar power generation is a non-linear scheme and whose parameters depend upon sunlight and temperature. The PV cell changes the sun-light into electricity[10, 11]. The PV array consists of parallel/series of PV modules. The cell is grouped together to form the panels. The voltage and current produced at the terminals of a PV system can be directly used to supply the DC load or connect to the utility system through an inverter. The schematic diagram of such system is presented in Fig. 3. The output of the PV system is tracked through MPPT technique to yield the maximum voltage and current at any instant. The MPPT generates a gating signal for DC-DC boost converter which produces a regulated and constant DC.

To convert this regulated DC into AC a DC/AC converter is employed. These converters are high rating power electronic devices (PED) which could be a voltage source inverter or current source inverter.

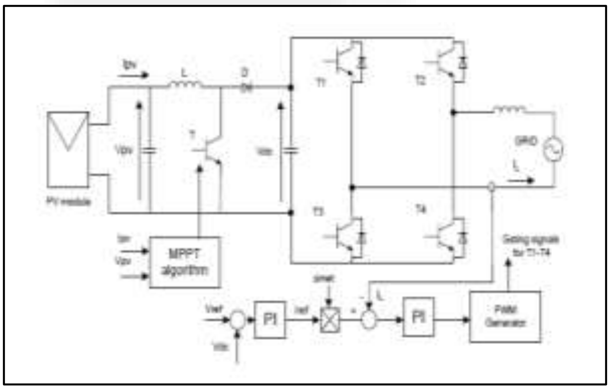

Fig. 3: Hierarchy of nanogrid system

The PV system is designed using 5 series and 1 parallel modules. The PV and VI characteristics are presented in Figure 4. The rated capacity of the Solar Photo-Voltaic (SPV) is 8000 W. The designed SPV is analysed for variable solar irradiation (100-1000 w/m2), output of PV is regulated using MPPT controller also, the controller helps in generating gate pulses for the DC-DC converter which is given in Fig. 5. The output voltage obtained is shown in Fig. 6 which is regulated in order to generate ripple free constant DC voltage. The output voltage of DC-converter is fed to the inverter connected to PV system to convert DC-AC. The tabular analysis of output voltage, current power with respect to varying irradiance is presented in table 1, and the corresponding graph is shown in figure 7.

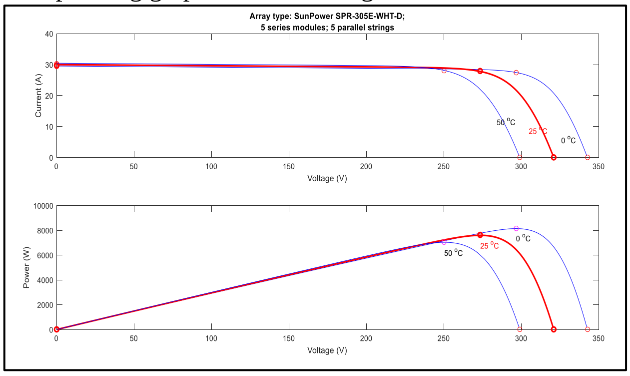

Fig 4 PV-VI characteristics 5x5 solar module

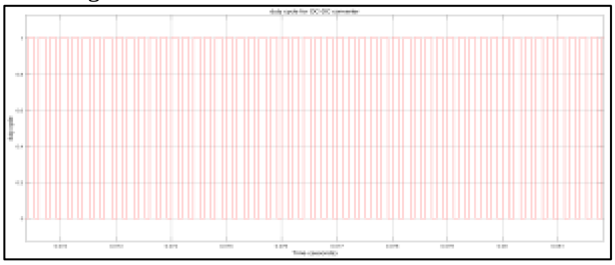

Fig 5 Gate pulse for the IGBT switch of DC converter

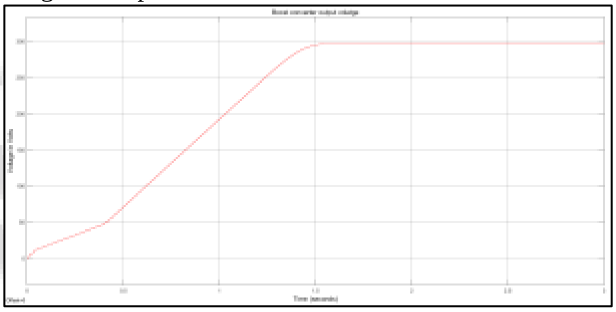

Fig 6 DC output voltage of DC converter

S.No.	Solar Irradiance	PV Voltage	PV Current	PV-Power
1	100	12	1.1	14.3
2	200	24	2.3	57
3	300	35	3.5	125
4	400	41	4.7	213
5	500	47	5.9	245
6	600	50	7	352
7	700	57	8.2	474
8	800	65.6	9.3	616
9	900	74	10.5	781
10	1000	81.8	11.7	958

Table 3.1: Solar generation at various irradiance

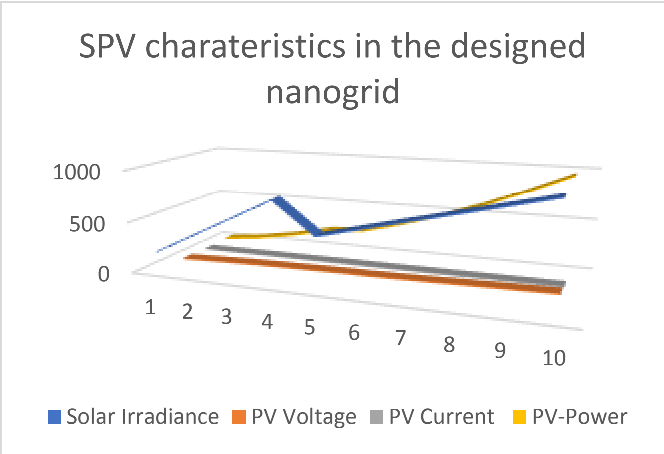

Fig. 7: Performance of the SPV in Nano Grid Design

IV. WIND POWER GENERATION SYSTEM

In this research work WPGS is designed using permanent magnet synchronous generator (PMSG). In PMSG excitation field is generated using PM, synchronous is a term referred to the system where rotor and magnetic field rotate with the same speed [18, 19]. The WT system incorporating PMSG is shown in Figure 8.

The Wind Power Generation System (WPGS) is designed using PMSG with 8.5 KW power rating. The WPGS is designed with sinusoidal back EMF and rotor type is round. The mechanical input given is torque "Tm" [20, 21]. The base speed is considered as 5m/s. The simulation model of the designed WPGS is shown in figure 9. The turbine model is shown in figure 10 with driver train model as presented in figure 11. The mechanical torque and rotor speed for the base speed simulation is shown in figure 12. The elctro magnetic torque is shown in figure 13. The line current, phase voltages and output power of the designed WPGS is shown in figure 14.

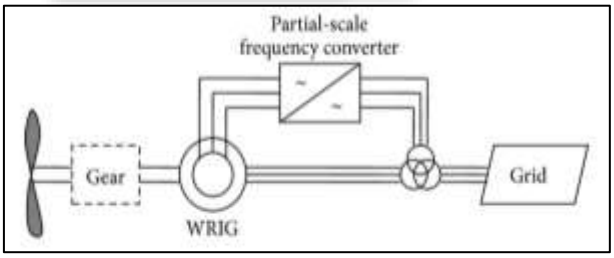

Fig. 8: Wind Turbine with a Permanent Magnet Synchronous Generator.

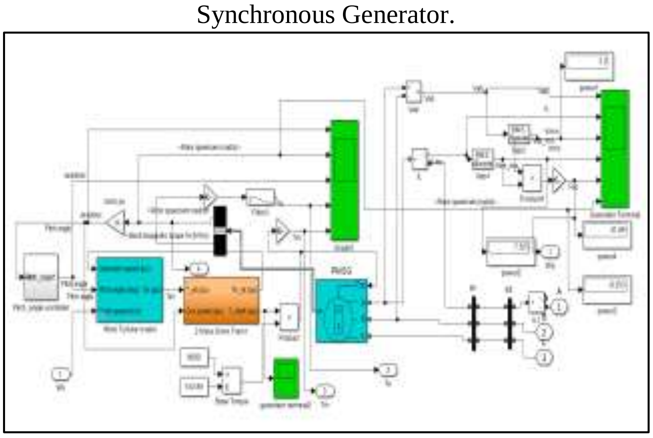

Fig. 9: Simulation model of designed WPGS

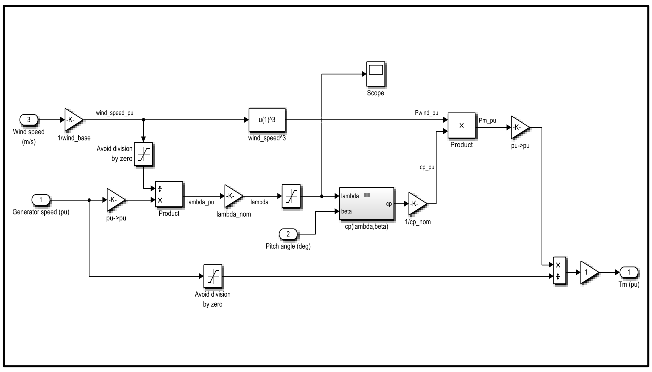

Fig. 10: Simulation model of wind turbine

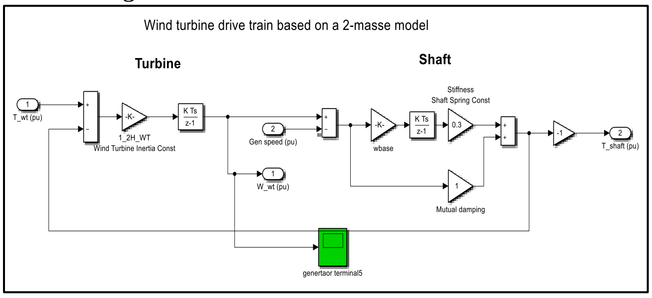

Fig. 11: Simulation model of drive train

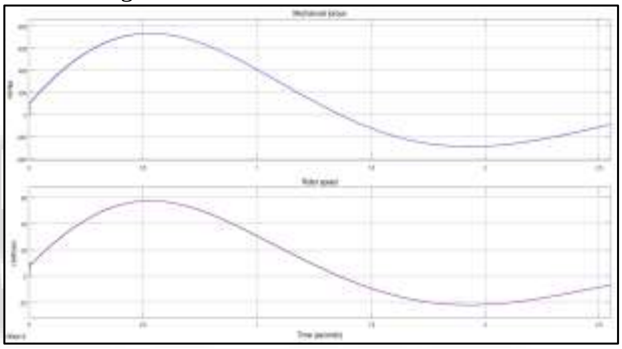

Fig. 12: waveforms of mechanical torque and rotor speed

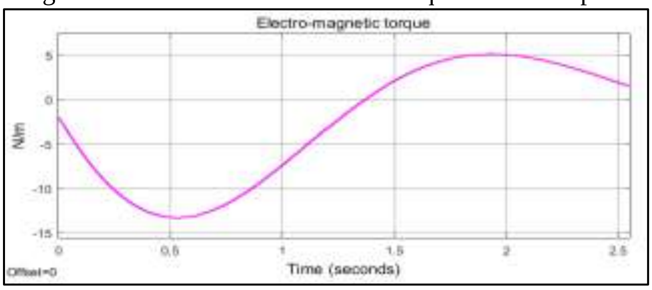

Fig. 13: Waveform of electromagnetic-torque

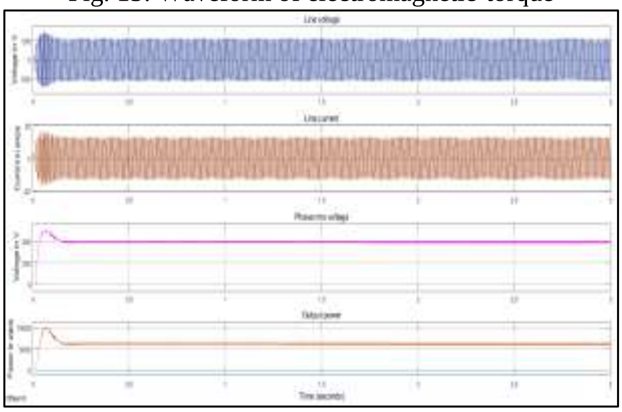

Fig. 14: Results of voltage current and power of WPGS

V. SIMULATION MODEL AND RESULTS

In this section performance analysis of the proposed work has been presented. The parameter selection of the proposed work is given in table 2. In the previous chapters result analysis of PV and WPGS system has been presented. It is observed that both PV system and WPGS give constant output both DC side and AC side at all wind speed and variable solar irradiation. This is the most important task when designing a PVW system since they are intermittent in nature and their output vary at variable environmental conditions. Another aspect of PVW system is that they must exhibit constant and synchronous characteristics with respect to utility system at PCC. The complete simulation model of the system design is presented in fig. 15.

Firstly performance of PV system is presented when it works is conjunction with the grid. The DC-converter voltage is shown in figure 16. The PV-voltage and power output is shown in figure 17. the voltage and current waveforms at AC side of the PV inverter is shown in figure 18.

Parameter	Value
PV rating	8 KW
PV voltage output	600 V
DC voltage output	300 V
Fundamental frequency	50Hz
switching frequency	5kHz
Boost converter inductor	150mH
Boost converter capacitor	100µF
Filter inductance	100mH
Filter resistance	0.01 ohm
Filter capacitance	1000 µF
DC voltage of WPGS	90 V
AC voltage of WPGS	200V
Rating of WPGS	8.5 KW
Load connected	10KW

Table 5.1: Design parameters

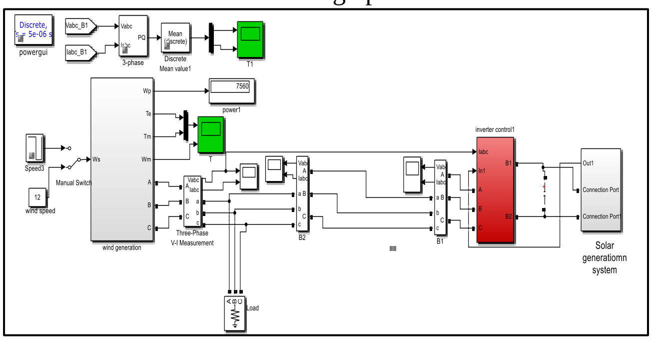

Fig. 15: Simulation model of the PVW- nano grid system

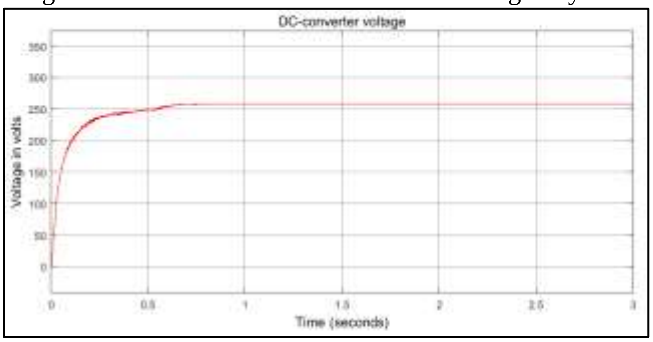

Fig. 16: DC voltage of DC-converter

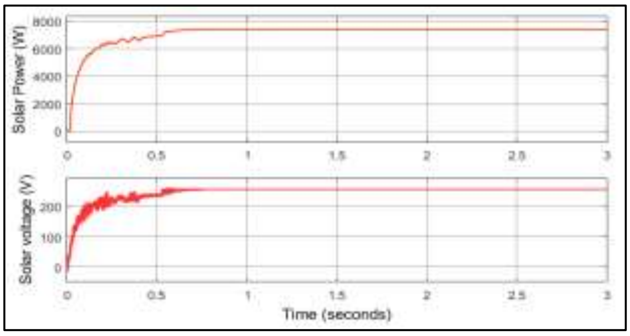

Fig. 17: PV voltage and power output

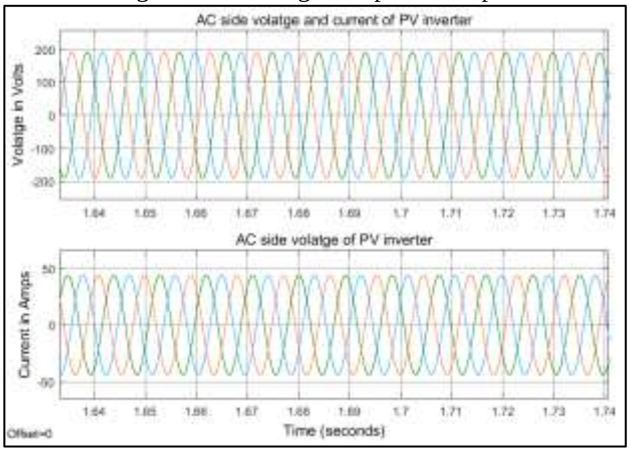

Fig. 18: AC side voltage and current of PV inverter

Next the performance analysis of WPGS forming a nano-grid system is presented when operated with solar. The mechanical characteristics of wind turbine system is shown in figure 19. Where, rotor angle in rad/sec, rotor speed, pitch angle, electrical and mechanical torque in N/m is shown. From the figure it can be seen that torque takes aprox. 1 sec. to settle to a fixed value and same is the case with rotor speed. The electrical characteristics of the WPGS is shown in figure 20. where, phase voltage line current and power output is shown. The AC voltage and current of the WPGS is shown in figure 21 which is synchronized and sinusoidal.

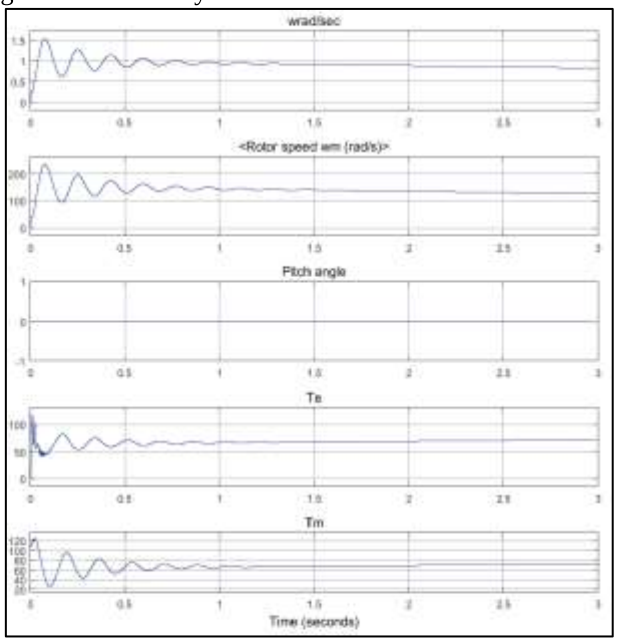

Fig. 19: Rotor speed and torque characteristics of designed WPGS

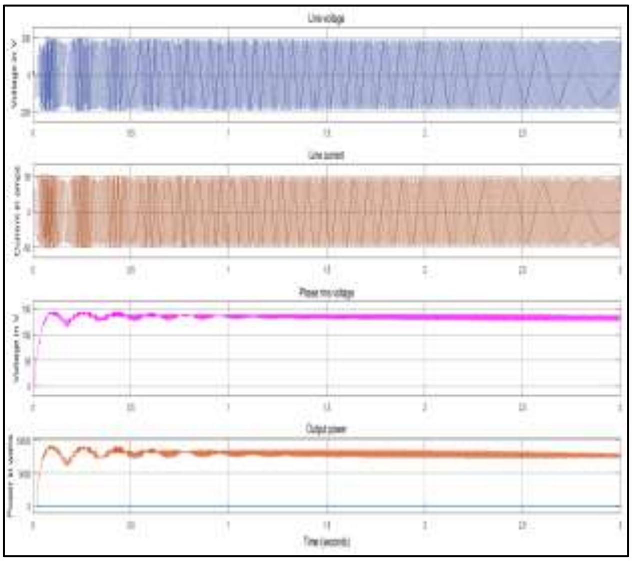

Fig. 20: Phase voltage, line current and power output of designed WPGS

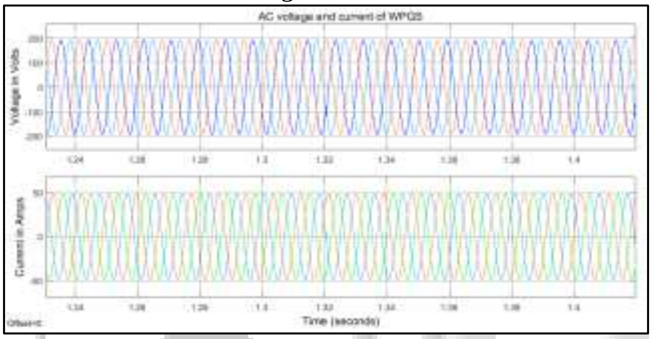

Fig. 21: AC output voltage and current of designed WPGS

VI. CONCLUSION

The examination on the hybrid nanogrid system is done, which was modeled in MATLAB simulation. Diverse qualities of the hybrid system were investigated for finding that how system operates to incorporate voltage stability and automatic load sharing capability control framework. This paper clarifies about the future extents of concentrate the wind and solar control incorporation in an electrical power framework. Author has demonstrated an ideal control of sources and loads to acquire control synchronism in the nanogrid system.

A brief note on papers published for the research on combine hydro and wind generation are presented in this work. It is observed that both PV system and WPGS give constant output both DC side and AC side at all wind speed and variable solar irradiation. This is the most important task when designing a PVW system since they are intermittent in nature and there output vary at variable environmental conditions. Another aspect of PVW system is that they must exhibit constant and synchronous characteristics. More-over the proposed topology give constant output for both PV system at variable irradiations and for WPGS system at variable wind speed. Also, when these system are integrated they also generate constant output both for voltage and current at PCC. The proposed system has been analysed for constant static three phase loading.

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