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SIMULATION AND MODELLING OF PV-WIND-BASED ON HYBRID POWER SYSTEM

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ABSTRACT

As oil and coal reserves are being depleted whilst at the same time the energy demand is growing, it is important to consider alternative energy generating techniques. Similarly there is a move from centralized power generation todecentralized power generation. Specifically within ruralcommunities where there is limited access to electricity, it is possible for decentralized renewable energy systems to make a large impact. This paper outlines the design of a hybrid power system consisting of solar photovoltaics(PV) power system,windpower system and battery storage. This system is designed for stand-alone operation. A novel controller links each of these components to ensure that one system is supplying the load dependant on the weather conditions. This system is modeled in PSIM and tested for various weather conditions and temperatures. The model and results are detailed in this paper.

Index Terms—Battery, Battery controller, Wind Energy, Solar PV, Hybrid Power system.

I. INTRODUCTION

It is an accepted fact that coal and oil reserves are declining; however human society's dependence on these fossil fuel resources is still on the incline due to high load growth and high rate of industrialization and economic development. Thus the need for cleaner, sustainable and viable sources of electrical energy are of utmost importance in order to ensure that the next generation enjoys the same economic development. In this regard, harnessing the wind and solar energy does not only preserve these resources but it also reduces pollution significantly by generating clean energy. Moreover, it is also important to see how these sources can be used for bulk power generation as well as small stand-alone systems for powering small and remote communities and villages or even islands. The electrification of remote areas was and still is very difficult and expensive, if it has to be done by extending the grid . For remote communities in these remote areas to be economically competitive in today's standards, the need for a sustainable form of electrification is extremely vital.

This paper presents a PV-Wind-Battery Hybrid Power Systems. Initially it looks at a standalone operation of a PV, wind and battery model and later looks at the operation of combined HPSs to improve the efficiency of the system to the load demand and lastly the controller to co-ordinate the PV, wind and battery systems.

II. SYSTEM BACKGROUND

Most Renewable energy systems require less maintenance and also have low operating costs compared to coal fired power stations. Individually, renewable energy sources are not reliable but on hybrid mode the reliability is significantly improved . The sections below outline the two renewable energy systems including battery storage. The last section focuses on the operation of these sources on a hybrid mode.

II.a. Wind Energy

Over the past two decades wind energy has been considered the fastestgrowing source for renewable energy; however wind energy is in abundance and is still underexploited. Wind is one of nature's unpredictable sources of energy, and to optimize in WECS potential, a detail study in weather pattern for a specific ideal site of installation is of utmost importance. The difficulty in WECS is controlling the speed and the direction in which the wind is blowing .The energy availability in wind is directly proportional to thecube of wind speeds.

Wind is a non constant variable.itchanges both in spaces and time. Most modern wind turbines today are HAWTs, the rotor orientation is usually classified according to HAWTs. Usually each turbine structure has two or three blades, and the blades design are either upwind or downwind.

II.b. Solar Energy

The abundant energy produced by the sun has a potential to meet our energy demand if and only if it is harvested properly and efficiently. Solar cell uses photovoltaic effect to convert solar radiation to electricity. The general solar cell model is considered to model the solar cell due it less computation and fairly accurate results . There are many maximum power point tracking techniques (MPPT), but only three were considered in this paper namely, the perturb-and-observe (P&O), incremental conductance, and the constant voltage.

II.c. Battery Storage

Although scientific development continues at an astonishing rate, the storage of electrical power is still a challenge. A battery system is very important in all stand-alone PV, wind, and hybrid systems. The battery system solves the inconsistencies that renewable energy offers . Lead-acid batteries compromises efficiency for longer charging and discharging cycles, which makes them ideal for renewableenergy systems and applications because they a designed for alengthy life span. Currently, Lead-acid batteries have a roundtripefficiency of approximately 75% and also a lifeexpectancy of 20 years.

II.d. Hybrid Power System (HPS)

The special legislation on energy which came into effect in 2003, forces energy producers to look at cleaner forms of generating electricity in order to combat global warming caused by green house gases. Most rural areas do not have access to electricity, and to provide electricity in these areas by increasing the scope of the electrical grid is often costly and has challenges. The focus nowadays is moving away from centralised distribution network to decentralized distribution networks where the generating source is located closer to the load .

The advantages of the HPS are outlines as below:

- Increases the efficiency and the reliability of renewable energy systems.
- Reduces the cost of the battery bank,
- Increase the life time of the battery since energy is being used as it is created,
- "HPSs allow longer variations in the average wind speed".
- HPSs provide about 26-40% saving as compared to PV-only systems.

III. HPS MODEL DESCRIPTION

The PV-Wind-Battery HPS model developed links the three power systems which are each capable of operating in standalone operation in order to ensure availability for load demand together. The controller developed for this system monitors the status of availability and connects the load to the available source. Fig. 1 shows the conceptual model of the PV-Wind-Battery HPS.

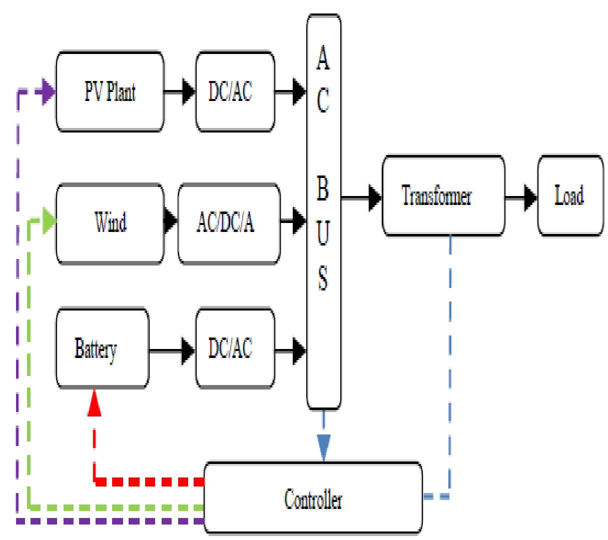

Fig 1.Block diagram of hybrid systems based on PV-Wind.

III.a. Wind Power System Model

The model considered for a Wind-Farm in this HPS is the wind turbine induction generator (WTIG). WTIG converts the mechanical power captured from wind to electrical power which the transferred to the grid via the stator of the generator.

The generator in this configuration is driven at a speed slightly higher than synchronous speed . The topology used in this paper allows a STATCOM to be used in order to provide reactive power control and also voltage control . Fig. 2 below shows the WTIG cascaded to meet the wind farm capacity of 4.5 MW. Cascading wind turbines in this configuration is advantageous because it provide redundancy during faults. The wind turbines in this topology uses pitch control shown in Fig. 3 to maintain the electrical power produced at 1 p.u.

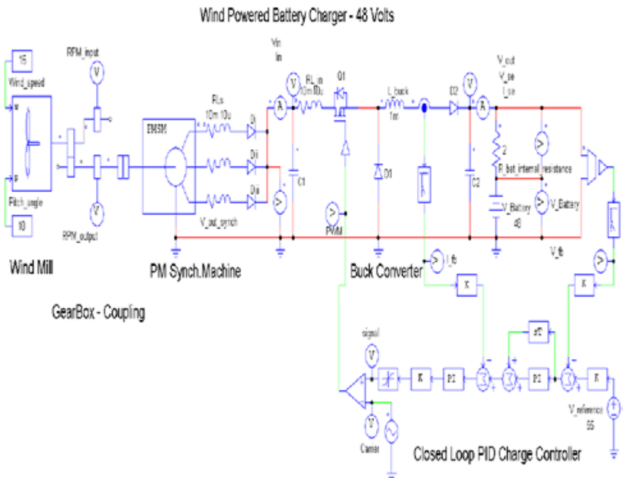

Fig : 2 Wind farm model

III.b. Solar Power System Model

The Schuco Photovoltaic Solar Module 185 Watt SP4 (2Panels)is used to simulate the PV plant using a general solarcell model for the PV module. This model has lesscomputation compared to the double diode solar cell modelwhilst the characteristic performance is fairly accurate.

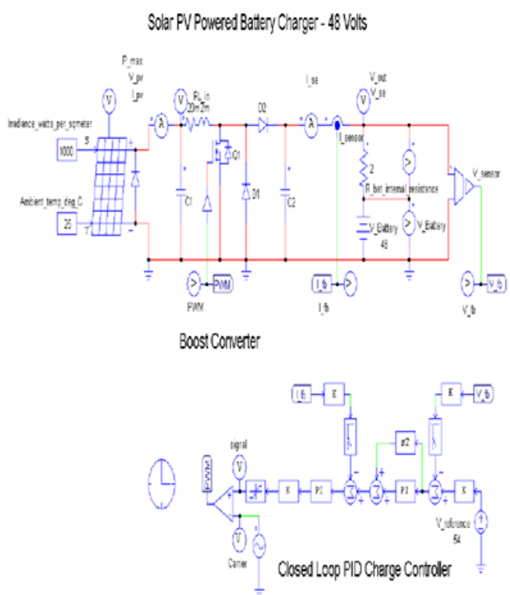

Fig : 3 PV Plant Model

The Perturb and Observe (P&O) algorithm is the most efficient control strategy for maximum power point tracking because it easily adapts to sudden changes in solar radiation. The P&O algorithm is applied to a PV-Array connected to a Cúk DC to DC converter. The perturb-and-observe (P&O) MPPT control scheme is commonly used for practical application in PV systems . This control scheme is preferred due to its simplicity in terms of implementation, it is highly reliable, and because of it high efficiency . Fig. 3 below shows the flaw chart of P&O algorithm.

III.c. Battery Bank model

The 400V, 6.5 Ah Lead-acid battery storage is used to simulate the battery bank connected to the load of 50kW at 50Hz. The DC machine included in this configuration is connected parallel to the load and also it acts as a generator to recharge the battery when the state of charge is 40%. Fig. 4 below shows the battery bank on standalone operation.

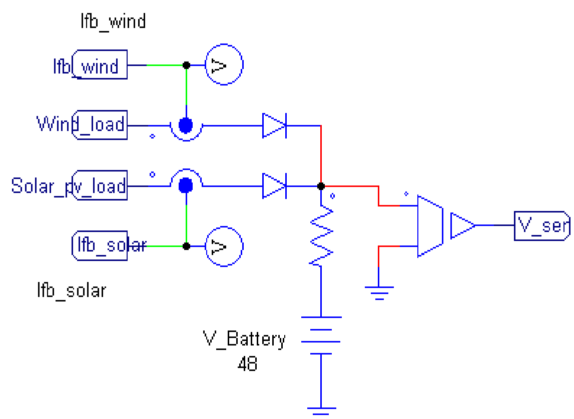

Fig : 4 Battery bank model

III.d. Complete model

These models are then linked and joined together in order to supply the loads as shown in Fig. 5. An AC Bus was chosen due to the nature of HPS in distributed generation where the load is near the source, hence the necessity of transmission of power over long distances in these networks is not an issue. AC to DC or DC to AC conversion produces harmonics which further complicate power systems and also escalate their costs; hence this paper focuses on reducing these harmonics producing agents as faras possible. The HPS system considered in this paper requires relay circuits to send signals to the controller about the state of availability, where the controller processes the information and makes a critical decision, these circuits operate far better and efficiently on AC signals than DC.

The AC Bus allows easier and economic expansion of the distribution network since the need for DC to AC converters is excluded as the load is supplied simply by tapping power from an AC bus to the load through a transformer.

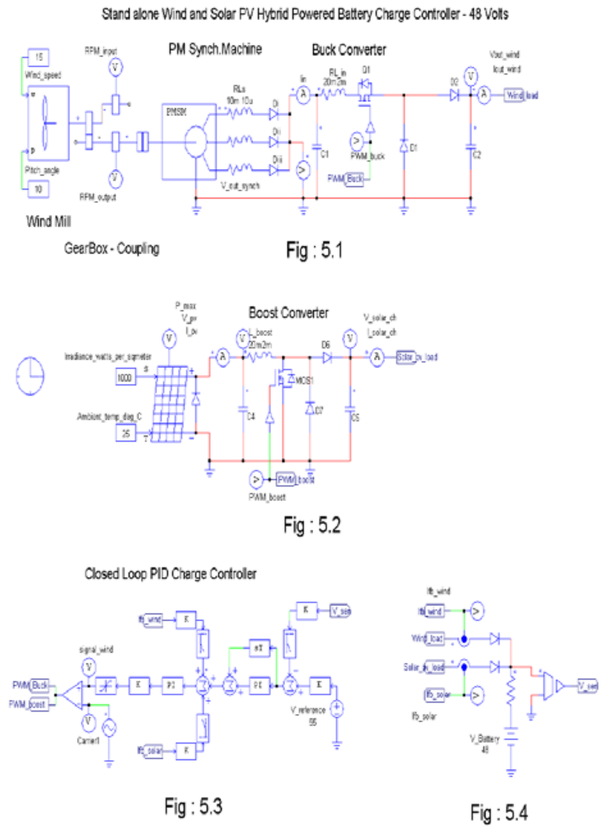

Fig : 5 Hybrid power system model
Fig : 5.1 Wind farm model
Fig : 5.2 PV Plant model
Fig : 5.3 Closed loop PID controller
Fig : 5.4 Battery bank model

The connection of these systems and the decisions of which system is supplying the load at what point in time is accomplished by controller designed specifically with that intention.

IV. CONTROLLER DESIGN

The controller developed for the HPS must adapt to the variations of weather. The control strategies presented in the flow chart in Fig. 6 highlights the overall control processes that are undergone by the controller to fully optimize the resources available in a HPS. The controller is driven by binary signals acquired from relay circuit via current transformer.

As this system focuses on the availability of either wind or solar energy, the controller senses the availability status of these energies and decides which power source the load is to be supplied from.

The HPS considered has a battery bank that provides power to the load during unavailability of the other sources.

The assumptions made in order to develop the control strategy for the PV-Wind-Battery HPS indicated in Fig. 5 are:

- The energy produced by these sources individually will be sufficient to power the load,
- The controller should use only one source based on availability to power the load,
- In case where two or more resources are available, the controller will decide which of the available sources will power the load and also what to do with the excess power generated,
- The controller decides when to charge the battery bank,
- The controller is to operate on a fully automated platform.
- The HPS operates in a normal steady state condition and development of additional functionality for the controller for abnormal or contingency conditions is identified as future work under the same project.

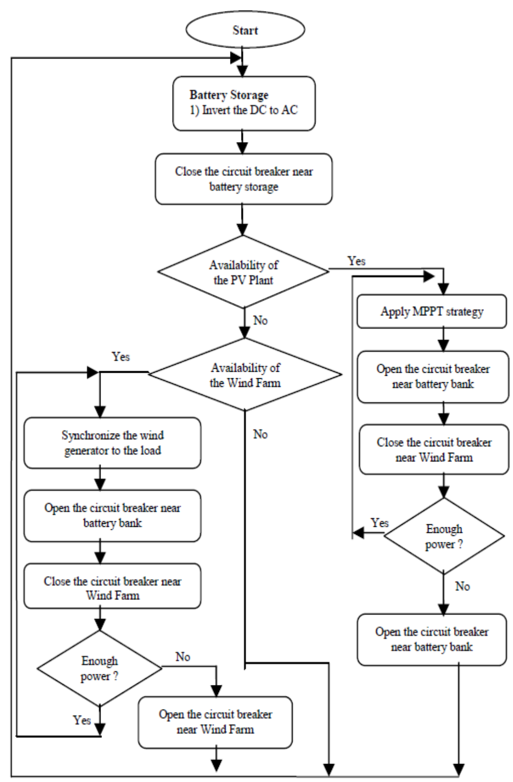

Fig : 6 Flow chart of the controller of HPS

VI.a. Cases to design controller

The case studies below were done on an ideal remote area from the electrical grid**.** The summary of these cases is tabulated on the Table 1 in a form of a truth table.

Case 1: None of the natural energy resources are available including the battery bank.

When there is no wind and the sunlight is also unavailable, the controller should keep the circuit breaker states as they are.

Case 2: On sunny day without wind.

In this case the controller should open all other circuit breakers and close the circuit breaker for the PV-Plant.

Case 3: This case also considers a situation where none of the energy resources are available excluding the battery bank.

When only the battery is the only available source of power, the controller should close the circuit breaker near the battery bank and open all other circuit breakers.

Case 4: This case considers a situation where the battery bank and solar energy are available.

When the battery ischarged and the PV-Plant are available to power the load, thecontroller should power the load through the PV-Plant byclosing the circuit breaker near the PV-Plant and open allother breakers**.**

Case 5: On windy day.

When the wind energy is the only available source of energy, the controller should close the circuit breaker near the Wind-Farm and open all other circuit breakers.

Case 6: On windy but sunny day.

When both solar and the wind energy are available, the controller should prioritize the solar energy over the wind energy by closing the circuit breaker near the PV-Plant and keep all other circuit breakers open.

Case 7: This case considers a situation where the battery bank and wind energy are available.

In this case the windenergy should take priority over the battery bank. Thecontrollers should closing the circuit breaker near theWind-Farm and keep all other circuit breakers open.

Case 8: This case considers a situation where all natural energy resources are available including the battery bank.

In this case also the controller prioritizes PV-Plant over other energy sources by closing the circuit breaker near the PVPlant and opens all other circuit breakers**.**

TABLE 1
TRUTH TABLE FOR HPS CONTROLLER

Inputs			Outputs		
0	0	0	0	1	0
0	0	1	0	0	1
0	1	0	0	1	0
0	1	1	0	0	1
1	0	0	1	0	0
1	0	1	0	0	1
1	1	0	1	0	0
1	1	1	0	0	1

The truth table in table 1 is designed based on the inputs signals to the controller. The controller is digitized to binary numbers by the outputs of the relay circuits which are directly linked to the inputs of the controller.

The truth table above results in the following Boolean equations:

$$O_{BS} = \overline{I_w}.I_{pv} \quad (1)$$

$$O_w = I_w\overline{I_{pv}} \quad (2)$$

$$O_{pv} = I_{pv} \quad (3)$$

Where *Ow*, *Obs*, and *Opv*are the the outputs of the hybrid controller, and *Iw*, *Ibs*, and *Ipv*are the inputs of the hybrid controller.

The Boolean equations above are used to implement the controller for the hybrid power system shown on Fig. 7 below.The controller trigger by the availability of wind or solar energy, if both these source are unavailable, the battery bank supplies the demand to the load. The circuit on Fig.7 below includes displays that show the state of availability.

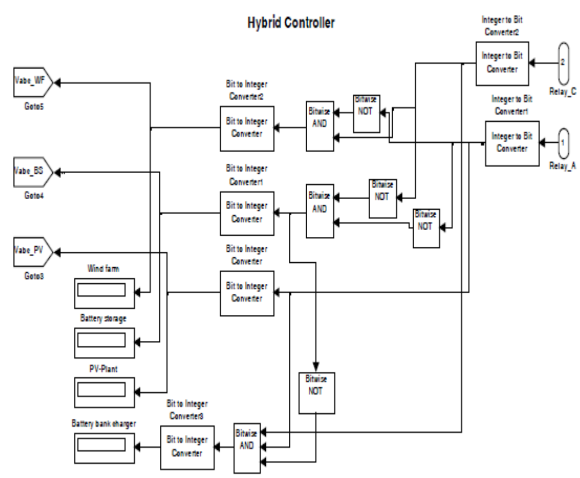

Fig : 7 Controller for hybrid power system

TABLE 2
TRUTH TABLE FOR HPS CONTROLLER

0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	0
1	0	0	0
1	0	1	1
1	1	0	0
1	1	1	0

Battery systems have a limited charge and discharge cycles. Using battery banks on hybrid power systems (HPS) increases the life span of the batteries compered to renewable energy systems on standalone applications. This increase in the life span of the batteries is due to the control of strategy employed by HPS as to when to charge or discharge the batteries. Table 2 below shows the truth table of the battery charger.

Equation (4) below implements the logic circuit shown on Fig. 8, it controls the circuit breaker between the wind farm and the battery bank. The battery bank is recharged if both the solar and wind energy are available provided that the battery bank's state of charge is below 40%.

$$O_{battery\_chapter} = O_w \cdot \bar{O}_{bs} \cdot O_{pv} \quad (4)$$

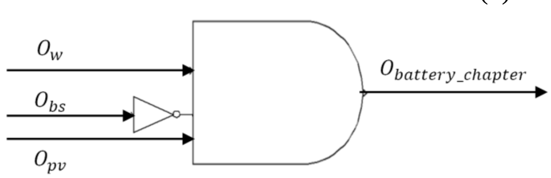

Fig : 8 Logic circuit for battery charger

V. RESULTS

V. a. Wind-Farm

The effectiveness of pitch control is demonstrated by Fig.9 and 10 below, where the mechanical power of turbines increases due to the increase in wind speed had non significant decrease and increase in voltage and current, respectively.

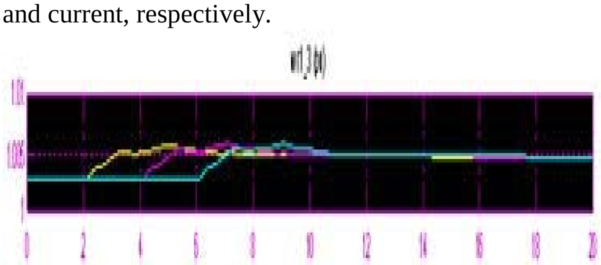

Fig : 9 Change in mechanical speed of wind turbine

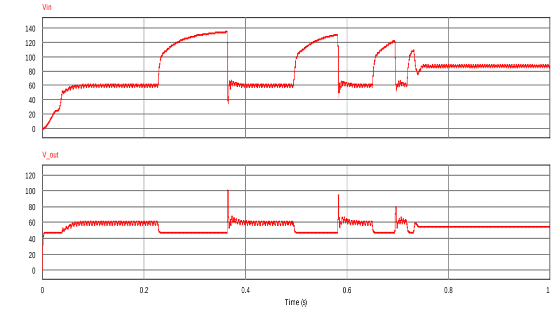

Fig : 10 Change in voltage and current.

V. b. PV – Plant

The simulation results for a PV-plant were generated based on a hypothesis that the behavior the cells in a MPE 185 MS 05 PV module is the same for all the cells in a PV array. Fig.9 shows the performance of the PV module using the general cell model under different solar radiation exposure. The green zigzag curve indicates maximum power point tracker using the P&O algorithm on Fig. 11.

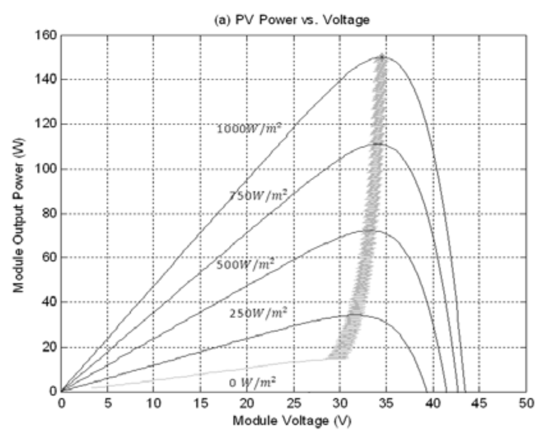

Fig : 11 The power-voltage characteristic curves

Table 3 below outlines the maximum power point conditions for PV-Plant under different radiation exposure. The increase in solar radiation increases the current produced by the array.

TABLE 3
THE PERFORMANCE OF THE PV-PLANT UNDER DIFFERENT SOLAR IRRADIANCE

Irradiance (E in /)	Open Circuit Voltage (in volts)	Maximum Power for an array(in Watts)	Maximum Power Voltage (in volts)	Internal Resistance for an array (in Ohms)
250	1254.5	974.4	882.0	778.90
500	1254.4	2018.8	926.8	413.35
750	1254.4	3108.0	952.0	287.56
1000	1254.4	4200.0	964.0	217.49

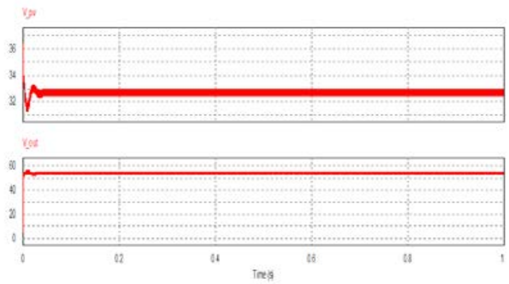

Fig : 12 The voltage waveform of the battery bank

V. c. Battery Bank

Fig. 12 below shows the performance of the battery bank over 100000 seconds. Initially the battery bank is charged to capacity, the storage can sustain this capacity for about 20 000 seconds while supplying the load.

V. d. Load

Fig. 13 below shows the line to neutral load voltage during of the HPS. The load voltage is maintained at 220V at 50Hz.

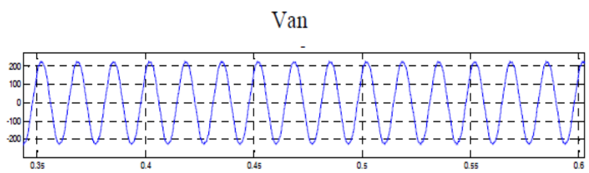

Fig 13 : Load Voltage

VI. CONCLUSION

HPSs require a very detailed survey on possible suitable sites. If deployed in an ideal location, these systems operate at a very low costs compared to the any fuel/coal fired plants. In distributed generation these systems will require less maintenance because they have fewer rotation components. HPSs therefore make a good alternative for power generation. The developed controller was tested with the simulations and proved to be very effective.

As some of the components within this model were modelled very simply, for instance the general model for the PV generation, some of the results were not quite as accurate as desired. The authors would recommend using more detailed models for each component, for instance using the double diode PV generation model, to give more accurate results for further work.

In addition this model does not take into account excess energy generated. Further work should include possibilities for using or storing excess generated energy in some manner.

This model and design of hybrid power systems is deemed to be very applicable to the authors' context in South Africa and it is found that this system would be well implemented especially within the rural African context. This technology would be able to be integrated in a rural context where there are no existing grids, by the use of microgrids. Microgrids are currently a large area of research and interest within South Africa and therefore this is a very relevant topic and this work can be very well applied in that context.

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