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Performance Analysis of a Direct Drive Small Wind Generator under Rectifier-Battery Load Conditions

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Abstract: This paper describes the rectifier-battery load testing procedure and performance analysis of a 1kW direct drive Axial Flux Permanent Magnet (AFPM) generator of a Small Wind Turbine (SWT). The generator was designed with large number of poles to improve its performance at low wind speeds, and its efficiency was found to be high with values of between 75-89%.The rectifier-battery load tests was performed to evaluate expected generator battery charging performance when operated in the field under low wind speed conditions.The two major parameters that were determined, and which formed the study objectives were the generator cut-in wind at which it begins to charge the battery and the efficiency of the rectifier, or battery charging efficiency. The generator wasfound to have a low cut-in-speed for battery charging at 154 rpm (about 2.8 m/s). The battery charging efficiency of the bridge rectifier was significantly high at 78%.

Keywords: Axial Flux Permanent Magnet (AFPM) Generator, Small Wind Turbine (SWT), Generator cut-in wind speed, Battery charging efficiency.

1. INTRODUCTION

Availability of energy services and appropriate energy technologies are vital for the social and economic development of Kenya. However, according to the World Energy Outlook (WEO) report of 2012 [1], Kenya is among the ten electricity poorest countries in the world. It is estimated that only about 7% of Kenya's rural inhabitants have access to electricity [2]. In these regions, energy needs are met by polluting and unhealthy energy sources such as traditional biomass (wood fuel and charcoal) and fossil fuels (mainly kerosene). Besides, where electricity is available, it is most commonly delivered to the grid, which suffers from power cuts and growing cost [3]. Small Wind Turbines (SWTs) are a viable option to electrifying rural areas with sufficient wind resources especially for regions where the grid is not present. The technology is available in a whole range of sizes and can fulfill rural energy needs at all levels of society. Smaller wind systems (<1kW) are suitable for household usage, small businesses and farmers whereas larger systems (>1kW) are more appropriate for electrifying institutions and village mini grids [4].

The interest in producing electricity from wind puts certain demands on the electrical machines and drives [5]. This challenge is what has led to much technological advancement in the development of innovative, direct driven, variable speed generators for wind turbines. The generator is an important component in a wind turbine, since it converts the mechanical energy in the rotating wind turbine to electricity. Small scale wind power applications require a cost effective and mechanically simple generator in order to be a reliable energy source [6]. Direct-drive generators fulfill this requirement by eliminating the need of gearbox in wind turbines. Gearless wind turbines have become popular because they prevent the drawbacks associated with the gearbox including oil leakage, gear costs, gear maintenance and gear losses [7].

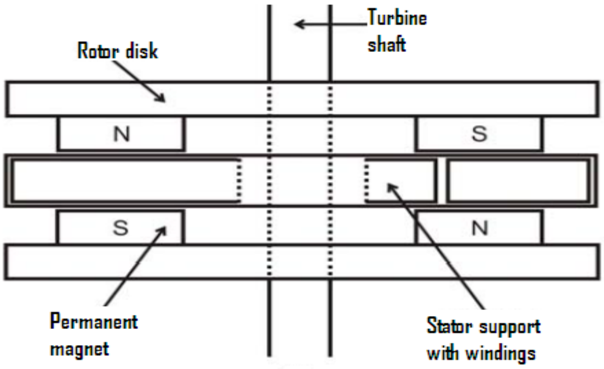

Figure 1: Structure of the double-rotor axial flux machine with air cored stator [9].

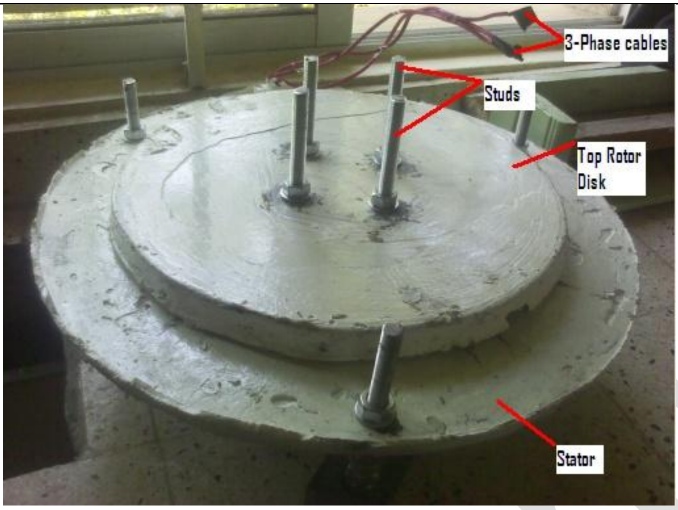

Figure 2: Assembled double-rotor AFPM generator

In this study, the double rotor air cored AFPM generator prototype was chosen as the most suitable based upon certain requirements. Among the requirements were that the generator design should be mechanically simple for ease of manufacture and maintenance even by those with basic technical skills and in small workshops. The generator must also be cheap to make and easily integrated into the turbine system. In addition it should be efficient, perform well under low wind speeds and produce no cogging torque to avoid any self-starting issues associated with some types of wind turbines.

The AFPM generator was successfully developed using locally available materials. Figures 1 and 2 represent the structure and the assembly respectively of the generator. The analysis of no-load test results for the generator has been published [8]. This paper provides rectifier-battery load test performance and analysis of the generator.

2. TEST LAYOUT

2.1 Power Control and Rectification Unit

The power control and rectification unit (Figure3) consists of a break switch, bridge rectifier, dump load, fuse (circuit breaker) and charge controller. The bridge rectifier converts open circuit AC voltage from the generator into DC voltages for charging the battery. The battery load is connected to the rectifier output. Figure 4 shows how the rectifier terminals are connected to a battery.

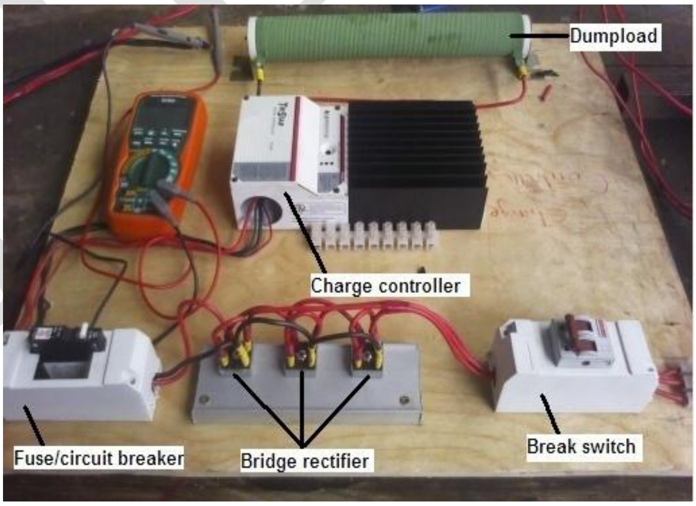

Figure3: The power control unit

During the rectifier-battery load test, the generator speed is varied at low speeds using a VSD connected to a motor and the multi-meter is used to measure electrical output power (current and voltage).

The rectifier-battery load test was performed to evaluate how the generator would operate in the field under low wind speed conditions.

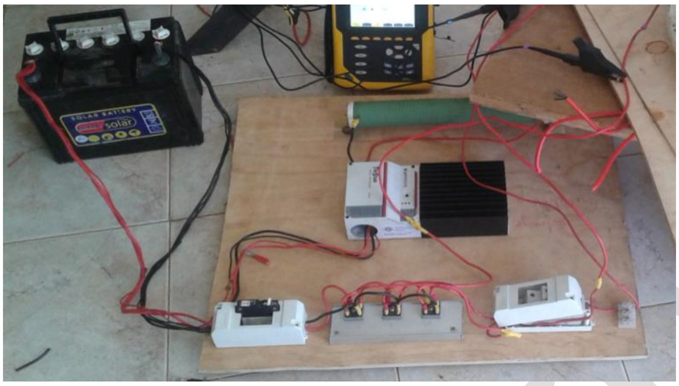

Figure 4: Battery load connected to rectifier output terminals

3. RESULTS AND ANALYSIS

The generator is run at low speeds and at short time intervals. The battery charging voltages and currents at the different generator speeds are presented in Table 1.

TABLE 1
BATTERY CHARGING VOLTAGES AND CURRENTS AT DIFFERENT SPEEDS

Speed (rpm)	**Charging Voltage (V)**	**Charging Current (A)**	**Charging Power (W)**
38	3.67	0.18	0.66
60	6.54	1.17	7.65
81	10.13	1.36	13.78
103	14.69	2.36	34.67
119	18.23	2.93	53.41
131	20.32	3.49	70.92
143	22.12	3.94	87.15
154	23.97	4.15	99.48
164	24.83	5.54	137.56
229	24.98	6.23	155.63
245	25.06	7.19	180.18
250	25.68	7.86	201.84
258	25.54	7.92	202.28

The generator begins battery charging when charging voltage reaches 24V because the generator has been designed for a 24V system. From Table 1, the generator speed of about 154 rpm (2.8m/s) produces battery charging voltage of 23.97V (approx. 24V) and current 4.15A. This speed is referred as to as the cut-in speed for battery charging.

Another observation is that at the generator rated speed of 250rpm, battery charging attains a peak voltage level of 25.68V which is about 7% above the battery system standard voltage of 24V. The voltage peaks because the battery system attains full charge condition. Graphs of charging voltage and charging current against generator speed are shown in Figures 5 and 6 respectively.

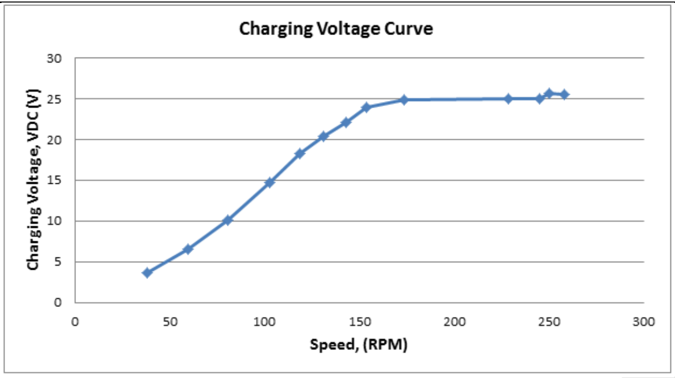

Figure 5: Graph of charging voltage against generator speed

As the battery continues to be charged (load increases) to rated value, the output power and voltage also increases until voltage reaches peak level (remaining nearly constant). At this point power produced also begins to decline (see Figure 7).

The maximum generator efficiency was found to be 89% [8]. However, some power is lost in the rectification process leading to low battery charging efficiency. The power loss is attributed to the diodes in the bridge rectifier as they usually experience a large drop of voltage across them at all times when in operation [10]. Charging efficiency at rated speed is about 69%, that is, the ratio of charging power at rated speed, 201.84W (Table 1) to generator output power at rated speed, 293W [8]. Therefore the efficiency of bridge rectifier is about 78%. Power loss in the cables also contributes to this low efficiency but use of more efficient diodes (like the modern bypass diodes) is recommended for improved charging efficiency.

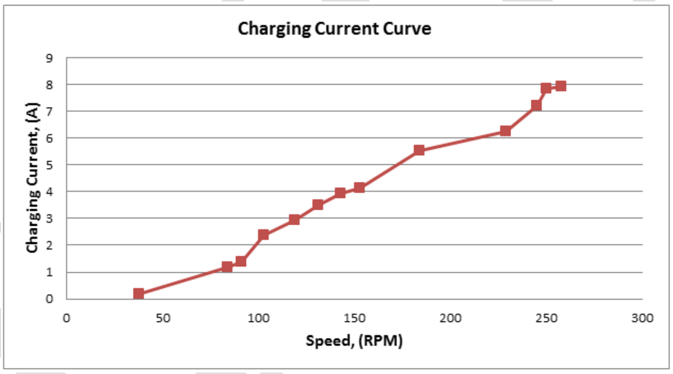

Figure 6: Graph of charging current against speed

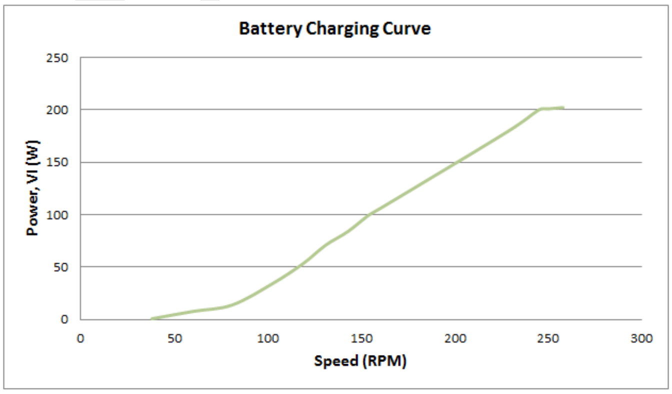

Figure 7: Graph of battery charging

4. CONCLUSION

The generator has a low cut-in-speed for battery charging at 154rpm (about 2.8m/s) making it suitable for applications in low wind speed sites. The generator is therefore a moreefficient electric power generation alternative to the drive-train combination of used motors and gearboxes found in the local market. It is also suitable for water pumping as opposed to the locally used but more expensive, bulky and high to maintain wind mills. The study has employed a combination of a VSD and motor for performance testing. This is a cheaper, faster and very effective option for generator testing that is also suitable for use in small workshops. Common methods of testing wind generators often employ the more expensive lathe machines and variable speed DC motors that are associated with bigger workshops. Finally, the low cut-in generator speed compensates for power loss in the rectifier even though for improved charging efficiency, further research is recommended to investigate the use of the diodes or replacement for the same.

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