

Modelling and Simulation of a Smart Instrumentation Mechanism for a Grid-Connected Household Hybrid Power System

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Abstract—Renewable energy technologies range from the well-established, such as hydropower, to the emergent, such as a wind-solar hybrid system. Each technology has its own individual instrumentation requirements to measure and control system variables. This project entails design and development of an effective instrumentation system for a hybrid solar-wind system for households, which will be able to transfer excess power produced into the national grid and establish participants to become independent power producers. Designing an instrumentation system for this hybrid system will require us to measure the following variables: Dc Voltage, Dc Current, Dc Power, Ac Voltage, Ac Current, Ac Power, Wind Direction and speed. Measurements and approximations to be used in this project are obtained from a study undertaken during a site visit to an existing solar system. They will be fed into the simulation using MATLAB-Simulink to be able to have a close estimate of efficiency and other parameters. Power produced in such a hybrid system can be used to supplement the already existing grid power. An effective instrumentation system as this is a bonus to the still under development smart grid systems, through the use of intelligent electronic devices (IED's) control commands can be issued to monitor the system remotely.

Keywords— *Photo Voltaic Cell, Instrumentation, Grid, Intelligent Electronic Devices, Hybrid System.*

I. INTRODUCTION

In rural areas in Botswana such as the cattle posts, 90% of households have realized the importance of renewable and clean energy sources as they employ the use of solar panels for charging their auxiliary devices such as cell phones and radio's. This has raised an important fact which is that rural areas have implemented and realized the importance of renewable energy technologies more than urban areas [1-3]. To curb this anomaly, a more accountable model is suggested in this project. As one of the objectives above stated, the development of the instrumentation system will entail households to sell their excess power produced from their own wind-solar systems to power utility companies. A smart metering system will measure excess power. Produced and

send it into the national grid, this will be recorded on the smart meter so that it can be claimed back. As mentioned in the project abstract, for effective mass deployment of renewable energy technologies, we need to have an intelligent electric grid or smart grid system whereby control, monitoring and islanding can be conducted without effort [6]. Our electricity infrastructure is on the cusp of game changing investments, embedding sensors, communications throughout the system from generation to consumers. These investments have opened entrepreneurial innovation and the single largest source of global warming pollution to vast new diversity of clean and renewable resources. The smart grid at its core will be facilitating the mass deployment of technologies such as the Hybrid power system this project is undertaking.

A. Why Hybrid?

In a hybrid power system, more than one type of electricity generation system is utilized. In some existing systems only one of the two sources is renewable and the other may be of fossil fuels. This approach is viewed as defeating the logic behind global warming as the extra non-renewable source is an addition to the already existing emission problem causing global warming. In this project a more direct approach to reduce a household's carbon footprint is taken. Intermittent energy resources such as wind and solar are very inconsistent, a hybrid of the two is more ideal.

B. Grid Connected

The usual practice nowadays is to link home based energy sources with the electric grid. This means that during the day the electricity generated by the PV system can either be used immediately or be sold to the utility corporations. In the evening when the photovoltaic system is non-operational the power can be bought back from the network. In analysis of this system, the grid acts as an energy storage system which makes having a battery bank optional.

II. LITERATURE REVIEW

A similar approach of designing a Hybrid power system was taken [4-5], in their case they proposed four renewable energy sources; wind turbine, biomass plant, photovoltaic modules and solar thermal modules. This novel approach was necessitated by wind and solar data collected from site which further proved the feasibility of the power system. The initial investment cost is a bit high for the average household but returns are rapid once the system is running fault proof and connected to the electric grid. Excess power sold to the utility price at the agreed local tariffs can lead to zero electricity bills for any consumer.

A similar project was carried out in [6-8] with control of the photovoltaic module and wind generation system being handled by a micro-controller

Design of a Photovoltaic panel entails connecting solar cells together such that each cell contributes a voltage of 0.6V to contribute to the final open-circuit voltage. Background knowledge on semiconductors is critical to design of an efficient PV module. Semiconductors are used as photovoltaic energy conversion devices through the p-n junction theory. To be able to alter the electrical characteristics of a material, doping is introduced such that there is an intentional introduction of impurities into its regular crystal lattice form. This process is what leads to the formation of p-n junctions in the materials. If the material being doped has more electrons in the valence gap (outermost shell) than the semiconductor, the doped material is referred to as an n-type semiconductor. Conversely if the material has fewer electrons in the valence gap than the semiconductor it is referred to as a p-type semiconductor. Current is able to flow as a result of the photovoltaic effect which is result of the p-n junction formations above. Before all this can happen a photon which is an elementary particle of light needs to enter a photovoltaic material. This particle can be reflected, absorbed or transmitted through. If absorbed by a valence electron, the energy of the electron is increased by the amount of energy of the photon. If the energy of the photon is greater than the valence gap energy, then this causes the electron to jump into the conduction band where it can now move freely. This electron can be moved back and forth using an electric field across the front and back of a Photovoltaic material. This mechanism is what creates the primary product which is a current or flow of electrons.

The efficiency of Photovoltaic cell is defined as the maximum electrical power output divided by the incident light power. Efficiency of a Photovoltaic cell is mostly reported at a cell temperature of 25°C and incident light at an irradiance of 1000W/m² which is one of the parameters used in the simulation of the Photovoltaic panel in Simulink [9]. In practice solar cells are either connected in series or in a parallel formation. Connecting them in parallel means the voltage remains the same but current is doubled and in series formation this means current remains the same but voltage increases.

A. Charge Controller

Charge controller is present in both of the energy sources. Since the scope of this report is on the solar side, more emphasis will be on it as the project is still on the solar model phase. A charge controller prevents the batteries from overcharging. Batteries used in this model are Deep-cycle lead-acid.

B. Batteries

Batteries are a requirement in hybrid power systems as they supply power during the night time when sunlight irradiation is not present or simply when the system cannot meet the demand. Selection of battery type and size depends on two factors which are load and availability requirements. Before the latter factors can be considered there is one critical one which is the area of placement. Batteries should operate without extreme temperatures, this means the area of placement should be well away from direct sunlight and ventilation should be present [11] Failure to observe this has reduced the life of some battery banks in previous projects. There are various types of batteries present in the market such as lead-acid, nickel hydride, nickel cadmium and lithium. A type is chosen depending on where it is going to be utilized. For instance car batteries which are lead-acid batteries are not designed to endure regular and repeated deep discharges which occur most frequently in battery banks designed for household loads. Renewable energy resources such as the one's wind and solar are intermittent in nature which means they fluctuate according to weather conditions which result in an unreliable power output. Batteries are a solution to this predicament as they supply a steady output.

C. Grid-Tie Inverter

A grid-tie inverter is a power inverter that converts direct current into alternating current suitable for injection into the national electricity grid. This is usually done at 120V RMS at 60Hz or 240V RMS at 50Hz. For successful integration with the grid, a grid tie inverter must satisfy the following conditions initially:

- The magnitude of the voltage output must equal of the grid
- The phase of the inverter output must be in synchronization with that of the grid
- The frequency of the inverter output must be equal with that of the grid.
- The phase sequence must also be in synchronization with the grid[10]

After the requirements above have been followed, the flow of real power and reactive power must be maintained. Real power is the portion of power that results when averaged over a complete cycle of alternating current waveform that produces a net transfer of energy in one direction. The Reactive power is the portion that is due to stored energy which returns to the source after every cycle.

In order to improve solar PV efficiency, there are various algorithms available that have been implemented. Such are the Perturb and Observe mechanism and the incremental conductance algorithm. Perturb and Observe mechanism aims to extract the maximum power that is available regardless of available temperature and irradiance. Research has shown that when load is directly connected to the system this decreases efficiency. It is based on the maximum transfer theorem which states that to obtain maximum external power from a source with a finite internal resistance, the resistance of the load must equal the resistance of the source as viewed from its output terminals. Initially the voltage and current are measured, their product which is power is sent to a decision node to determine whether the input power is greater than or equal to the measured power during last iteration. If this condition is true, the same process of comparing the input voltage with last input voltage is done. On a Yes result, a decision is taken to increase voltage and vice versa for a No result.

The Perturb and observe algorithm is one mostly used to obtain the maximum power point; it has its shortfalls which other algorithms capitalize on. Such disadvantages of the P&O algorithm are that it may not be able to track the peak power under fast varying atmospheric conditions. This is due to the fact that it operates in a way of a control system which has to produce feedback for the next inputs to be implemented. If it cannot cope with the rapidly changing conditions the maximum power point may not be discovered every cycle. The perturb and observe mechanism is shown in Fig.1.

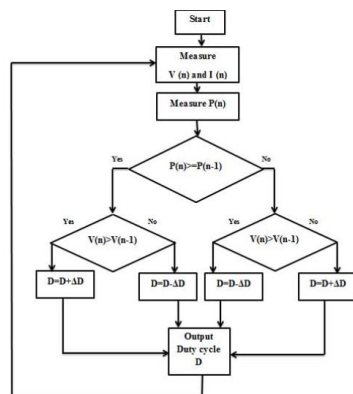


Fig.1. Perturb and Observe Algorithm

III. SIMULATION OF THE PROPOSED SYSTEM

The Fig.2 shows the complete photo voltaic system. Fig.3 and Fig.4 explains the simulation diagram for load switch controller and complete battery charge controller and battery banking system. The MATLAB code above has two functions which work to break and open when called upon by the IF conditions. If the state of charge of a battery is 80% or greater, the battery may start supplying the load. Internally this entails breakage of the links of the PV source to avoid overcharging. When the state of charge of the battery reaches 40%, the PV

Array breaker links are closed triggering opening of the load breaker links and beginning of charging.

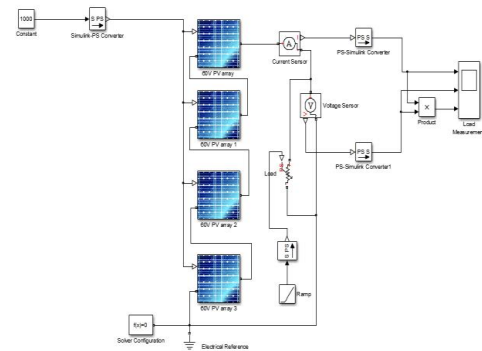


Fig.2. Complete Photo Voltaic System

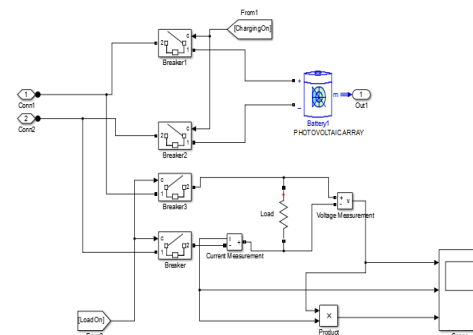


Fig.3 Load Switch Controller

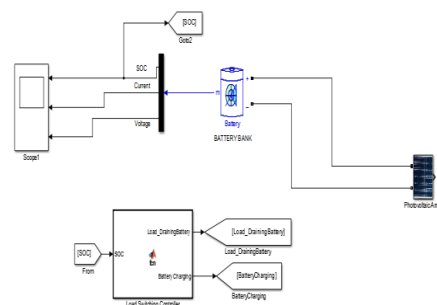


Fig.4. Complete Battery Charge Controller and Battery Bank System

IV. SIMULATION RESULTS

The Fig.5 shows the current output waveform and the Fig. 6 shows the voltage output waveform. The Fig.7 shows the

power output. The battery bank performance results are shown in Fig.8, Fig.9 and Fig.10.

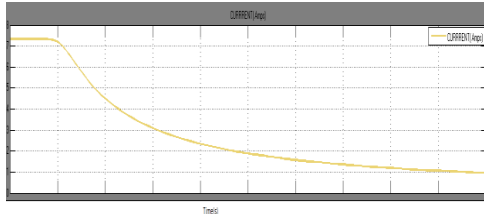


Fig.5. Current decreases from 7Amps with time as the load is connected to the hybrid system

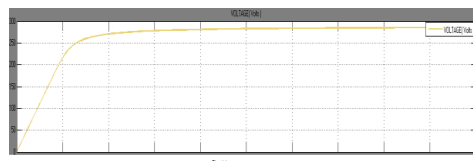


Fig.6. Voltage rises from 0v to a steady state value of 270v

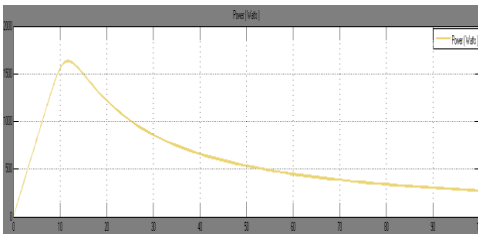


Fig.7. Power Output

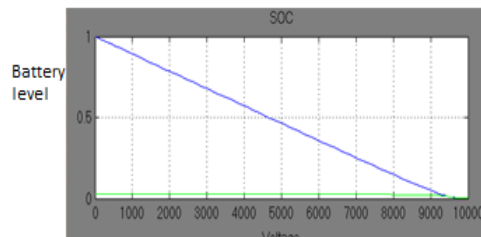


Fig.8. Battery Bank Current

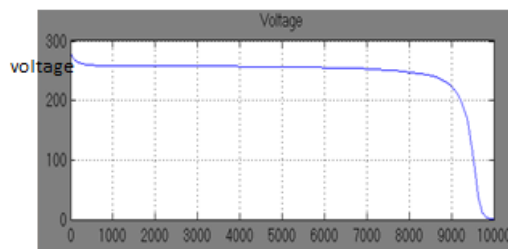


Fig.9. Battery Bank Voltage

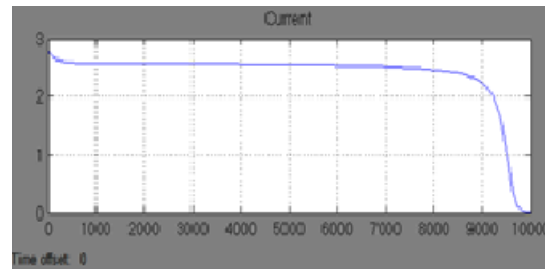


Fig.10. Power supplied to loads by battery bank

IV. CONCLUSION

Hybrid power systems are the way to go in this time and age in order to fully harness our natural resources and reduce the earth's carbon footprint. If every household was to have such as system installed, the energy crisis would be solved.

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