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# Abstract

Renewable energy systems are an increasingly popular way to generate electricity around the world. As wind and solar technologies gradually begin to supplant the use of fossil fuels as preferred means of energy production, new challenges are emerging which are unique to the experience of decentralized power generation. One such challenge is the development of effective monitoring technologies to relay diagnostic information from remote energy systems to data analysis centers. The ability to easily obtain, synthesize, and evaluate data pertaining to the behavior of a potentially vast number of individual power sources is of critical importance to the maintainability of the next generation of intelligent grid infrastructure. However, the application space of remote monitoring extends well beyond this.

This paper details the development and implementation of an open-source monitoring framework for remote solar energy systems. The necessity for such a framework to be open is much better understood when considered through the lens of the theoretical potential for remote monitoring technologies in developing countries. The United States and other industrialized nations in the so-called ‘first world’ are likely to be slow to seriously adopt renewable energy on account of the massive investment and infrastructural changes required for its integration into existing electrical grids. In countries where grid infrastructure is generally inadequate or nonexistent, this barrier is far less of a concern, and renewable energy technologies are viewed more as an enabling tool for progress than as a disruptive and expensive technological tangent. In this context as well, remote monitoring has a role to play.

Of course, renewable energy systems are nothing new in the developing world—they are just inaccessibly expensive to most individuals. Still, international charity organizations have been integrating renewable energy technologies such as solar power systems into their development projects for more than 40 years. In Sub-Saharan Africa in particular, most of these efforts have resulted in failure. Chief among the culprits responsible for these failures are the implementing organizations themselves, who almost pathologically fail to transfer the knowledge required to maintain renewable energy systems to local stakeholders. While a pervasive lack of access to technical training in most developing countries does not bode well for the success of future endeavors to promote electrification—rural or urban—it is arguable that remote monitoring systems would be of nontrivial assistance in such efforts. Of course, cost is still the greatest barrier to entry with respect to any given technology in the developing world. Therefore, *this* project revolves entirely around the use of open platforms and inexpensive, generic technologies to produce a viable remote monitoring framework for use in environments where the resources and general knowledge required to maintain renewable energy systems is particularly scarce.

# Introduction

Remote monitoring is not a new or unsolved problem. Therefore, the rationalization for pursuing this particular project requires some explanation and a description of the context in which the necessity for open-source remote monitoring arises. Furthermore, some vocabulary needs to be modified for specificity’s sake. Renewable energy systems encompass a vast range of technologies, but in particular this project is concerned with solar technology. Additionally, the results of this project, while arguably generalizable to any given solar application anywhere in the world, are specifically intended to demonstrate how remote monitoring can be made useful and affordable in developing countries. Finally, so as not to make callous generalizations about the homogeneity of the so-called ‘developing world’, the requirements for this project have been designed with the realities of poverty and underdevelopment specific to Sub-Saharan Africa in mind. The applicability of the results of this project in a different region or environment is left for others to decide.

## *1.1 Road Map*

In order to argue for the need for open-source alternatives in solar remote monitoring, it is important to demonstrate the unsatisfactory nature of the status quo. To do this, certain premises need to be established, in order.

1. By some mechanism, photovoltaic technology is a sufficiently common alternative to the use of grid-powered electricity in Sub-Saharan Africa, enough to the point where generalizations about its use can be made.
2. In many situations in Sub-Saharan Africa where solar power systems are implemented, these systems quickly fail as a result of poor maintenance.
3. While the proper maintenance of solar power systems requires regular to intermittent attention on the part of trained individuals, a significant portion of the maintenance process is an information technology problem.
4. An information technology solution in the form of a remote monitoring system can serve a critical role in providing system overseers with the information required to maintain solar power systems.
5. Existing solar remote monitoring systems are expensive, limited in their application, and for the most part proprietary.
6. Such a system should be available as an open-source technology because of the economic realities of poverty and underdevelopment in Sub-Saharan Africa.

Arguing for these premises will establish the proper context within which to discuss the requirements for this project and evaluate the results of this semester’s attempt at such an implementation. Thereafter, a discussion of future implementations, abstractions, and applications can be discussed in a productive way. The overall purpose of this thesis, much moreso than a description of an implementation or a celebration of achievement, is to serve as a proof of concept that solar remote monitoring is neither expensive nor particularly cumbersome to implement and thus warrants further investigation and development by the open source community. There are many applications for a system like this. Monitoring a solar power array is just one of the possibilities. Practically any device with measurable outputs running in a remote environment represents a potential future extension of this project. The hope, of course, is that others will be able to build upon this framework and use the results described here to cultivate their own applications. Advancements in this field can yield cheaper and more robust solutions to assist in both the maintenance and viability of remote solar power systems.

# Background and Literature Review

The first logical premise to establish in the defense of this thesis is the assertion that solar technology is a more or less commonplace method of alternative energy production in Sub-Saharan Africa. The second is that many solar energy systems fail as a result of misuse. Because these two premises are generally part of the same narrative when discussed in the context of development in Sub-Saharan Africa, they will be established together in this section through an in-depth analysis of three separate case studies. To begin, however, it deserves to be stated that when we consider the notion of solar power as common we are discussing the subset of people who actually have access to electricity, and thus generalizations drawn from studies of the utilization of solar energy systems are capable of only limited abstraction.

## 2.1 Solar Energy and International Development

In 2002, the African Energy Research Policy Network (AFREPREN) published an article in Energy Policy magazine which estimated that roughly 68% of the inhabitants of Sub-Saharan Africa live in rural areas without access to grid-powered electricity. In the conventional interest of development and poverty reduction, the question of how to provide modern energy services to this enormous proportion of the population is of critical importance. As many African governments have proven incapable or unwilling to tackle this issue, the general consensus of the international development community at large has been to emphasize the dissemination of renewable energy technologies to rural areas. This focus on localized power generation has in turn led to the implementation of a variety of developmental programs involving the use of solar technology to provide generally inaccessible communities with electrical power for important infrastructure like schools and hospitals.

Now, short of making the problematic assertion that electricity is a solution to poverty, suffice it to say that the status quo has prompted many charity and non-governmental organizations (NGOs) to use solar energy systems in conjunction with their humanitarian development efforts. With this context in mind, arguments can be framed about best practices for sustainable development and the role of remote monitoring in renewable energy projects.

## 2.2 Solar Energy Case Studies—Popularity and Practicality

How has solar technology fared as a solution to the pervasive and systemic lack of access to electricity in Sub-Saharan Africa? This is not a question which can be disputed on account of the maturity of the renewable energy approach. Rural development projects in Sub-Saharan Africa involving the use of photovoltaics for electricity generation have been underway since the 1960’s, and, therefore, the accumulated body of literature on this subject is vast. Upon examination of this literature, the most striking observation to consider is the general lack of theoretical disagreement among case studies. This is not to say that experience of every solar project or private initiative has been similar; rather, that they all seem to succeed or fail for similar reasons. In rudimentary terms, there has been a great diversity of contextual experiences with solar technology. In Zimbabwe, for example, the United Nations Development Program Global Environment Facility (UNDP-GEF) project from 1993-1997 seems to be the reigning example of overall failure, while the Nyimba Energy Service Company (ESCO) project in Zambia in 2000 and the Namibian government’s ongoing ‘Home Power!’ program appear to be shining arguments for the continued proliferation of solar technology.

Overall, these projects were both introduced into comparably poor rural communities, however, the character of each project’s implementation was markedly different, and the end results appear to reflect this. The experience of the UNDP-GEF project seems to have left the reputation of solar technology permanently scarred in some circles. Nevertheless, solar technology remains popular. In some ways, it appears that independent of the direction of the community of non-governmental organizations solar technology continues to find its way into the hands of those who can afford it. There are plenty of viable alternatives to solar technology as far as energy generation goes, and therefore the phenomenon of solar technology’s continued popularity is of particular interest to analyze and explain.

### *2.2.1 Solar is popular…*

Ray Holland, a member of the Intermediate Technology Development Group (ITDG), argued in an issue of IEEE Review in 1989 that the cost of solar technology needs to fall considerably before it can be used for applications in developing countries beyond communications, lighting, and water pumping. Today, 20 years later, this is still the primary barrier to the increased dissemination of solar technology. In spite of this, however, solar technology remains a popularly sought after and highly demanded commodity in Sub-Saharan Africa. The reason for this may be explained in part by the observation Holland makes that the over-consumption of electricity is generally not a problem for rural communities. The fact that solar technology can provide high-quality lighting and allows for the use of radios, small television sets, and cellular phones is enough to fuel the continued demand for panels and batteries. Mark Hankins and Robert J van der Plas, in their research for the World Bank's Energy Sector Management Assistance Program (ESMAP) in Kenya in 1998, concluded that between 75% and 90% of rural Kenyans *know* about solar technology. While not conclusive, they argue that the continued popularity of solar technology may be attributable to just that—its popularity. Absent readily available information about other sources of renewable energy such as wind turbines, efficient biomass combustion, and micro-hydroelectric generators (which are argued by some to be better suited for rural energy needs), it is probable that rural dwellers aspire to own solar panels because it is a symbol of relative social status and represents a step out of poverty.

### *2.2.2 …But should it be?*

Two researchers for AFREPREN, Stephen Karekezi and Waeni Kithyoma, conducted an evaluative study of renewable energy strategies for rural African communities in 2002. Their main criticism of contemporary approaches to energy generation on the part of international development organizations is actually the gross *over*-emphasis of solar technology. Karekezi and Kithyoma are keen to point out that solar systems are woefully inaccessible to the vast majority of rural communities. Citing the failure of previous micro-finance and subsidy-driven solar distribution programs, it is consistently estimated that around 80% of the rural poor in Sub-Saharan Africa cannot afford even the smallest 18W solar power systems, let alone keep up with service and maintenance fees. Putting relative costs into perspective, for a 40-50W solar power system, it is estimated that most rural households would have to pay on average 200% of their per capita GNP just to afford start-up and installation costs. In the United States, this percentage would amount to an average cost of $50,000 for the same system. Additionally, Karekezi and Kithyoma argue that home-based energy needs in Sub-Saharan Africa are 90% to 100% comprised of cooking and heating. As solar technology is generally limited to lighting and communication, it is hardly a viable or worthwhile investment for most rural families to purchase even the smallest solar power system.

However, Karekezi and Kithyoma do admit that solar technology can be employed to provide quality lighting and offset the need for fuel-burning light sources. In fact, solar is actually preferable to biomass in terms of lighting. Biomass applications produce low-quality light and require the continued purchase of fuels for combustion, whereas solar technology combined with high efficiency CFLs can perform for many years with relatively little maintenance. This also goes to directly offset a large portion of the exposure to smoke particulates created by combustion lighting, (which is an altogether different public health crisis that is beyond the scope of this paper). It is not Karekezi and Kithyoma’s purpose in their analysis to completely discredit the application of solar technology, as they do recognize the usefulness of the services it can provide insofar as lighting, entertainment and communication are concerned. They do, however, stress that solar is quite limited in its application and should not be at the forefront of renewable energy strategies for rural development.

### *2.2.3 The UNDP-GEF Project*

The analysis of Karekezi and Kithyoma is important as an African perspective on current energy paradigms. While it is clear they are opposed to the dominance of solar technology in rural development strategies, it is important to consider the context from which they draw their criticisms. One of the major case studies that exemplifies the failure of development projects involving solar technologies is the UNDP-GEF program in Zimbabwe from 1993-1997. The GEF project was one of the largest efforts by the UNDP in history to proliferate the use of solar technology, and the fact that its results are so widely criticized deserves examination. In a May 2000 article of *Energy Policy* magazine, Tim Jackson, Tinashe Nhete, and Yacob Mulugetta published a comprehensive article on the lessons of the GEF project. Jackson and Mulugetta are researchers from the University of Surrey Center for Environmental Strategy (UK), and Nhete is an ITDG member from Harare, Zimbabwe.

The main criticisms that Jackson, Nhete, and Mulugetta cite, overall, are the lack of rural stakeholders in the projects’ success, and the lack of post-project follow-up by the UNDP. In a nutshell, the project was a donor-driven program to install 10,000 environmentally friendly solar power systems in Zimbabwe’s rural areas over the five-year period between 1993 and 1997. From the very outset it can be argued that the project was overly ambitious and attempted to address the concerns of too many incompatible interests. In the report on the project released by the UNDP in May 2004, the mission statement includes the achievement of the UN Millennium Development Goals, the satisfaction of environmentalist concerns regarding greenhouse gas emissions, the alleviation of rural poverty in Zimbabwe, and the creation of new markets for local solar companies. In the attempt to satisfy all of these goals at once, the GEF project spread itself very thin and failed to do much beyond meeting donor funding deadlines. In the *Energy Policy* article, the GEF goal of reducing global carbon emissions by installing environmentally friendly technologies in rural areas of Zimbabwe is correctly likened to “using a sledgehammer to crack a nut.” It is an ostensibly ridiculous assumption to say that rural communities in Sub-Saharan Africa have an even measurable impact on global carbon emissions, and it is an act of blatant hypocrisy to impose upon them such limitations as a prerequisite for development aid.

### *2.2.4 Critical Implementation Failures*

Despite the wrong-headedness of the GEF project from the outset, critical failures were made during the project’s implementation which undermined the likelihood that the systems put in place would remain functional for much longer than the project itself. While some of the solar power systems were donated to rural communities, the majority of them were sold through micro-financing schemes. In this respect, the most common problem facing the proliferation of solar technology was again brought to bear. Only 20% of rural households in Zimbabwe could afford even the smallest solar system offered to them by the GEF project. In this respect, the locally affluent became the primary benefactors of the project rather than the rural poor. Moreover, emphasis on spurring private sector solar industries was given priority over the transmission of knowledge to the owners of solar power systems. In turn, local solar technology suppliers and businesses were the only resource rural communities had when they experienced system failures as a result of misuse.

On its head, this is not an entirely unworkable situation. Technical knowledge of solar system design and implementation is a marketable skill and should be allowed to seek professional outlets. The problem arises, however, when the owners of solar power systems have *no* understanding of how their systems work and must pay local technicians for even the most minor causes of concern. Over time, it was found that a majority of people misused their systems without realizing why, and were then burdened by the increased costs of maintenance and repair.

### *2.2.5 The Problem of Maintenance: Battery Care*

The most common problem was the routine overuse of batteries. Solar power system owners were not educated on the basic principles of battery care, and were not aware of their system’s limitations. Thus, they routinely left electrical loads on until their battery banks fully discharged and their appliances cut off. (Solving *this* problem in particular is one of the primary goals of the remote monitoring system described in this paper.) Then, without knowing the consequences of consistently over-discharging batteries, this practice was repeated until the battery electrolyte was depleted and could no longer hold charge. While this is the eventual fate of any rechargeable battery, understanding safe discharge limits can double or triple battery longevity. At the very least, if solar power system owners were simply taught that they should only leave their lights and appliances on for a certain amount of time so as to prevent their batteries from completely discharging before allowing them to recharge, it is likely that many of the UNDP-GEF systems would have lasted much longer. (This may be overly optimistic, as revealed by the results of the next case study.) The way the UNDP-GEF project was conducted and the overemphasis placed on the role of local technicians led to many systems failing far before they should have. Many solar power system owners then replaced their failed batteries with cheaper and more affordable car batteries, which, unfortunately, are not designed for the charge cycling of a solar power system, have fewer amp-hours, and, in turn, would end up failing soon after. While a robust understanding of the physics involved in this process is useful, it is not necessary to solve such problems. Much of the failure of the UNDP-GEF project to create lasting improvements in rural communities is hinged on the fact that they did not transmit even the most basic knowledge of solar power system ownership to the project’s benefactors.

### *2.2.6 The Problem of Maintenance: Local Technical Support*

Part of the reason the importance of a basic understanding of solar power system maintenance and care seems to have been overlooked by the UNDP-GEF project was that it was hoped this void would be filled by the growth of local businesses and technicians. In the interest of time, perhaps, this was wishful thinking on the part of the UNDP-GEF project planning staff. It also appears that another casualty of the UNDP-GEF project’s donor-imposed time constraints was the formation of a stakeholder community. No local or international NGOs, rural authorities, or patrons of any sort were procured prior to the full fledged implementation of the project, much to the dismay of observers in Zimbabwe and elsewhere. The UNDP-GEF project, it seems, was constrained so tightly by its five-year commitment to install 10,000 solar power systems that it forgot most everything else and left the responsibility of repairs, maintenance and education up to unproven and—more importantly—*undesignated* local actors.

### *2.2.7 The Pitfalls of Scope*

Another unfortunate complication of the UNDP-GEF project was that its immense scope had the unintended consequence of undermining the long term viability of local solar technology businesses. The introduction of the raw equipment for over 10,000 solar power systems into the local market dramatically distorted the prices of system components. The parallel market which formed in the midst of the UNDP-GEF installations also took a toll on the ability of registered solar technology businesses to function. Cheaply made amorphous silicon panels from South Africa made their way into Zimbabwe and began to compete with the more expensive multi-crystalline silicon panels supplied by the UNDP. Panel theft also became a problem. Solar panels are valuable commodities and are easily removed from rooftops as a result of the necessity that they are open and exposed. The primary targets of theft were women, the elderly, and the disabled. The resultant fear of criminals and the loss of such a large investment made some potential buyers of solar power systems turn the opportunity down. This, combined with the onslaught of economic downturn in Zimbabwe, drove many of the newly formed solar power companies out of business in a relatively short period of time. In 1997, there were roughly 60 registered solar companies to service 10,000 new customers as a result of the UNDP-GEF project. By 2000, there remained only 15. Of the businesses that survived, the vast majority of them had been in business prior to the UNDP-GEF project. Today, with inflation rates in Zimbabwe above 1 million percent, it is doubtful that even the strongest of these solar businesses still exists.

### *2.2.8 The Lack of Follow-Up*

Unfortunately, there is no post-project data on either the UNDP-GEF project systems or the businesses it tried to create. The reason for this, while hardly surprising given the circumstances, was that the UNDP had not planned on making any post-project assessments and instead assumed that this data would be collected by local solar energy companies. As over 75% of the businesses created by the UNDP-GEF project failed within three years, there is today no data on the performance of *any* of the 10,000 installed systems.

The experience of the UNDP-GEF project tarnished much of the popular support among some NGOs for similar endeavors. However, it deserves to be stated that the UNDP-GEF project was poorly executed and failed in a rather predictable manner. The tiger’s share of the blame in this instance can be laid at the feet of the UNDP for their almost inspired incompetence and their treatment of communities of interest in the project moreso as a commodity in service of an environmentalist publicity stunt than as the intended benefactors of a serious and rigorously researched effort at promoting sustainable rural electrification. Fortunately, while the UNDP-GEF project may be sadly representative of the general experience of NGO projects involving solar energy systems, other projects have been much more successful, despite being faced by similar challenges.

### *2.2.9 Glimmers of Hope: The Nyimba ESCO Project*

The failure of the UNDP-GEF project is humbling, but nevertheless deserves to be countered with examples from smaller, but more effective development efforts involving solar energy systems. One such example of a successful solar energy program was implemented by the Nyimba Energy Service Company (ESCO) in Nyimba, Zambia in 2000. In this case, the introduction of solar technology had a positive impact on the lives of people in rural communities, particularly with regards to educational prospects. Mathias Gustavsson and Anders Ellegaard, two researchers from Goteborg University in Sweden, reviewed the progress of this ESCO project in a 2004 article of *Renewable Energy* magazine.

An ‘ESCO project’ is a new type of technology-dissemination program which has been employed in a variety of contexts and communities around the world with considerable success. The Nyimba ESCO project consisted of 100 individual solar home systems installed in rural communities near the town of Nyimba. The general philosophy of the Nyimba ESCO project is that expensive technology such as a solar power system is beyond the purchasing capability of most rural dwellers and should therefore be given as a service package, whereby clients enter into a contract providing them with the installation of a 50W solar home system in exchange for a monthly service fee of 25,000 Zambian Kwacha, or the equivalent of U.S. $6.85. This service fee covers any problems that may arise during the time clients use their solar home system, including the replacement of parts if they are damaged. The contractual system was composed of a 96 Ah deep cycle battery and charger, a 12V, 50W PV panel, and four 7W CFLs for lighting, including fixtures. As the combined wattage of the CFLs is only 28W, clients were encouraged to buy their own appliances to make use of the rest of their solar home system’s capacity. This was meant to endow clients with a sense of ownership in the maintenance of their solar home system; of course, most of the need for technical expertise was intended to be accounted for through monthly servicing fees.

### *2.2.10 Poverty and Servicing*

The unique facet of the Nyimba ESCO project compared to other case studies from Sub-Saharan Africa is the fact that people who would not otherwise be able to afford a solar home system are given the opportunity to use one for a small monthly fee. In practice, however, this fee was still a barrier for many households. The results of Gustavsson-Ellegaard study found that 90% of the households with solar home systems contained at least one formally employed person. The division in incomes is again made clear here, as it was found that between 10% and 15% of households with solar home systems found it extremely difficult to pay their fees. Nevertheless, it was also found that around 50% of clients did attempt to expand and maximize the use of their solar home systems, some of whom even managed to purchase and install inverters to run an appliances requiring alternating current (AC) power. Overall, however, most households acquiring a solar home system felt that the primary benefit of solar technology is the availability of quality lighting at night.

### *2.2.11 The Benefits of Solar Technology*

The benefits of quality light manifested themselves quite vividly qua the experience of the Nyimba ESCO project. The Gustavsson-Ellegaard study found that nearly 60% of clients claimed they could not read at night prior to having a solar home system, and 50% believed that children were the primary benefactors. Around 89% of households with a solar home system claimed that their children used the available light at night to study, whereas only 42% of households without a solar home system could claim that their children attempt to study at night. Interestingly, it was found that children would study together at night in houses with solar home systems. Furthermore, teachers began to use the advantage of having dependable light at night to teach classes. Extremely poor children who cannot afford schooling and who must work to support their families during the day were able to benefit from classes taught at night. This was also found to be the case in Namibia (the next case study), and thus it points to the educational promise that solar powered lighting may indirectly hold for rural communities in Sub-Saharan Africa.

The ability to expand one’s active day was cited as another benefit of having a solar home system. Twenty percent of businesses owners claimed they could expand their working hours after dark with the aid of dependable lighting. Beyond this, the desire to own a television set was repeated in the Gustavsson-Ellegaard study as greater than the desire to have a solar-powered water pump. This seems to point to a consistently exhibited desire on the part of rural communities to have access to appliances and commodities that allow for entertainment and increased communication with the outside world. As one teacher in Nyimba was paraphrased as saying, “Our lifestyle changes; it is like we moved from the rural area to the town. We now have light in the evenings and we can play music.”

### *2.2.12 The Recurring Problem: Battery Care*

Still, amid this apparent success in Zambia, some of the pitfalls of the UNDP-GEF project were also found to exist. A general lack of knowledge among clients absent the support of technicians seemed to lead to the overuse and failure of batteries. The Gustavsson-Ellegaard study revealed that even with the regular monthly support of local technicians that 25-30% of the installed battery banks failed after only 2 years of use. The life-span of an average deep-cycle battery is in the range of 5-8 years. It is thought that if systems were operated a bit more carefully that this life-span could be increased, but the underlying point remains that lack of training on the proper care of battery banks is one of the chief reasons that solar power systems fail when introduced into rural environments.

### *2.2.13 Glimmers of Hope: The Namibian Home Power! Program*

Throughout this discussion of the various experiences with solar energy in Sub-Saharan Africa, it deserves reiteration that development projects in this context tend to succeed or fail for similar reasons. In situations where the owners of solar power systems are trained on the use of battery banks and/or local technicians are specifically *designated* as system overseers, these systems can be of great and lasting benefit to rural communities. In situations where this does not happen, they rather quickly fail. To further establish this point, another successful solar energy program worth mentioning is the Namibian governmental ‘Home Power!’ program.

Njeri Wamukonya, a researcher for the United Nations Environmental Program Collaborating Centre on Energy and Environment in Denmark, prepared an evaluation of the Namibian government’s post-independence efforts to gradually expand the electrical grid to all parts of the country. To date this has been an enormous endeavor, and thus the Namibian government has launched a low interest rate loan program called Home Power! through which rural and semi-rural communities can purchase home solar power systems. The program provides applicants with a solar home system installation to be paid back over a maximum of five years at a 5% interest rate.

The experience of Namibia has been similar to that of the rest of Sub-Saharan Africa in the sense that, again, only a minority of rural households seem to be able to afford even the smallest PV systems, and therefore localized elites tend to gain more from the dissemination of solar technology than do the rural poor. In fact, the Home Power! program does not grant installations to applicants who do not already make enough money to afford the systems.

### *2.2.14 Stakeholder Cultivation and Knowledge Transfer*

The Namibian government has committed itself to the development of its grid infrastructure and popular electrification in a way that NGO and donor-led programs simply cannot sustain for any considerable length of time. Furthermore, the Home Power! program, in contrast to the UNDP-GEF debacle, is a long term effort and does not have deadlines to install a specific number of solar power systems into random rural communities. Home Power! involves the contracting of local suppliers to install systems properly in client’s houses and emphasizes the transfer of knowledge regarding maintenance and installation between technicians and clients. This is a responsible action on the part of the Namibian government to attempt to prevent its installments from being wasted on account of misuse. This is a critical point: The Namibian government has drawn from the general corpus of knowledge on the performance of solar power systems in Sub-Saharan Africa, and their policy *reflects* the fact that training clients on the maintenance of their systems, regardless of their technical background, is one of the most crucial aspects of a successful solar energy dissemination program. There are national radio programs, advertisements, and TV commercials in Namibia intended to educate citizens on the proper use and limitations of their solar energy systems. This kindles local businesses, encourages proper usage of solar power systems, and promotes the technology around the country.

An interesting note about the Namibian Home Power! program is that recipients of solar home systems, by virtue of the fact that they understand exactly what their system can and cannot be used for, report almost universally that their welfare improves after installation. (Interestingly, households with off-grid power do not have to deal with blackouts and actually have more consistent lighting than do their counterparts in urban areas!) The primary benefits of quality lighting and solar technology are reported as the ability to read at night, listen to radio, and in some instances watch television. Above solar water pumping or any other appliance, surveys indicate that the first things people with solar arrays desire to run are television sets. This allows people to watch news and keep updated on national affairs, watch sports, and in general provides a greater sense of connectedness with the outside world. Such additions to rural people’s daily lives, while primarily aesthetic in nature, are widely reported as marked improvements over life without electricity at all.

## 2.3 Lessons Learned From Case Studies

The case studies listed here have been chosen for their exemplar nature in demonstrating the realities of the utilization of solar energy in Sub-Saharan Africa. Of course, some synthesis is required to crystallize and properly abstract the lessons of these experiences. An obvious question that arises from the case studies is why solar energy, given its costs and limitations, makes any sense in the first place as a developmental motif in Sub-Saharan Africa? This is a valid question, but not one to be explored in any critical depth here. Perhaps unsatisfyingly, this project does not attempt to derive an “ought” about the use of solar energy from the “is” of its use by development organizations and governments as a way to promote rural electrification. The premise that remote monitoring can help in the maintenance of solar power systems is only to be established as a statement of fact. This thesis makes no attempt in any serious way to assert a preference that solar energy “ought” to be used in Sub-Saharan Africa or that this project “ought” to be employed, but rather that if the proper functioning of such technologies is considered desirable, then this is one viable solution.

Moving on, the case studies discussed here are sufficient to demonstrate the first two premises of the justification for this project, that 1.) Solar technology is a commonly used alternative to conventional grid-powered electricity and 2.) That many solar power systems fail as a result of misuse. However, the evidence from these case studies also establishes the first half of the third premise, that trained individuals are necessary for the proper maintenance of solar power systems. This is a fairly trivial point, but one that is made all the more poignant by the positive experience of the Namibian Home Power! program. When both the owners of solar power systems and technicians in the local community are involved in the maintenance process, systems last longer and perform better. In retrospect, the obvious nature of this fact does not seem to have occurred to the UNDP during the GEF project. Why not? Unfortunately, this is unsurprising in the broader context of international development. Humanitarian development and charity organizations have long been the subjects of scorn in academic circles for their pathological ignorance to some of the most obvious truths about sustainable development.

### *2.3.1 Sustainability in Theory and Practice*

Sustainability is an ironic topic in the field of humanitarian development projects because it is so often emphasized in theory but almost always bungled in practice. Consider the espoused benefits of renewable energy systems versus the practicality of their application: As has been shown, right off the bat, solar energy falls flat on its face as a practical investment for poor and rural communities because it is astronomically expensive given the services it provides and the relatively meager economic returns it can yield through income-generating activities. In most situations it is simply a material impossibility to afford. Thus, in the vast majority of cases where solar technology actually finds its way into the hands of otherwise underdeveloped and impoverished communities in Sub-Saharan Africa, it is only through the work of governments and, more commonly, international charity organizations. As a result of this dependency, the sustainability of development projects involving solar power systems is tenuous. Solar energy may provide a theoretical source of clean, renewable, and essentially ‘free’ electricity, but its initial cost is so high that it usually necessitates external intervention.

Moreover, one of the major problems with the introduction of expensive and potentially complicated technology into underdeveloped communities is the concept of cost after installation. Once a new piece of infrastructure is in place, a permanent maintenance cost has also been introduced. If a solar array is installed on the roof of a school, a technician will have to routinely look after it, and that technician’s time and skill-set cost money. But how can an already impoverished community afford such expenses? And where does the knowledge come from?

In the case of the UNDP-GEF project, this entire aspect of the long-term sustainability was ignored. The rest is history. In the case of the ESCO project in Zambia, while the same criticisms can be leveled with respect to the failure of some systems in the hands of owners without proper training to maintain them, the fact that a community of locally designated technicians was established had an impact on the project’s success. Of course, the scope of these projects may limit how much can be abstracted from them. The UNDP-GEF project involved 10,000 individual systems whereas the Zambian project only involved 100 individual systems, and the Namibian project is ongoing. In general, of course, it is almost always the case that proper training translates to better maintenance.

Financing schemes are a more difficult issue to resolve. The programs in Zambia and Namibia were both instituted under the assumption that the initial cost of installation, (absorbed by the implementing organizations at the outset) would be eventually be repaid by the recipients of solar energy systems. The UNDP-GEF sold the majority of its solar power systems through micro-finance schemes, and donated the rest. It is likely that an important tenet of promoting stakeholdership is a realistic concept of cost on the part of project benefactors. Still, it is clear that after-installation costs must as low as possible. Realistically there is almost no up-front or after-installation cost that will be low enough for the poorest rural families. But on this note, we are again faced with the inherently unsustainable notion of external dependency. Conventionally, when development organizations try to fill the gap in knowledge and resources referred to above, they do so in patently unsustainable ways, or, as was the case for the UNDP-GEF project, not at all.

### *2.3.2 The Conventional Approaches*

Some common approaches to nurturing development projects after their inception include the establishment of effectively permanent international fund-raising schemes (such as the approach taken by World Vision) or the periodic sending of NGO personnel to maintain a given project themselves. While the development projects identified in the aforementioned case studies were met with various levels of success, they were all implemented by comparatively reputable organizations. This is unfortunately not the general case. In the broader context of international development, there are quite literally thousands upon thousands of development organizations. The actors that partake in the creation of these organizations are from all walks of life and relative levels of competency. It is a curious commentary on the seriousness with which some of these efforts are undertaken that, for instance, community organizations in the United States (high schools and church groups alike) will of their own volition take on the challenge to go to countries in Sub-Saharan Africa with the explicit intention of starting development projects. This is not to say that such efforts are in bad taste, but rather that no officiating body outside of these groups themselves can actually validate their qualifications to undertake the projects they initiate. This is an extremely problematic and questionable practice. An example is useful at this juncture, of course. Invisible Children, a US-based child soldier advocacy group, partakes in fundraising efforts to supply former child soldiers with school supplies and educational scholarships. While these sorts of actions are conventionally considered benign, Invisible Children also uses the colloquial leverage they gain through such community activism to actively attempt to engage in peace talks between warring factions of the ongoing Congo-Ugandan border war. This is almost unbelievable considering the fact that Invisible Children is run by former students from the University of Southern California’s school of Cinema Production. Quite frankly, who sanctions the legal opinions of the Invisible Children staff on the nuances of humanitarian crises in Uganda or the tentative international agreements set up to end cross-border warfare between Uganda and the Democratic Republic of the Congo?

This question is of course asked rhetorically, and this is admittedly a tangent in the general direction of this thesis. The point of the above discussion is to help characterize the nature of these independent so-called development organizations. Among such groups, as the analysis of Karekezi and Kithyoma points out, solar technology is sometimes unjustifiably popularized. Solar projects tend to have a popular aesthetic because of their perceived relationship with environmentalism and sustainability. This does not mean that solar is an applicable or even effective technology in a given environment. Still, the commercial qualities of solar technology are of course realized by development organizations engaging in projects that have the secondary quality of being used for fundraising efforts. The British writer and researcher Alex de Waal, in an edition of the *African Issues* book series, discusses this apparent conflict of interest in his book *Famine Crimes: Politics & the Disaster Relief Industry in Africa*, expressing the fact that development organizations must favor the aesthetics of their projects in the eyes of potential donors moreso than their actual effectiveness. This is precisely the problem faced by the UNDP-GEF project in its attempt to address the issues of global warming while simultaneously bungling a rural electrification campaign. Considering the lackluster performance of larger, more established development organizations to succeed in the creation of sustainable development programs, it is of great consequence to wonder just how the legions of disreputable independent organizations are faring with their projects that also happen to involve the use of solar energy. While official data on the actions of these organizations is by definition scarce, it is dubious that they have fared much better.

The aforementioned development strategies, by and large, are problematic because in general they tend to indicate a failure to thoroughly consider how best to *sustainably* empower communities of interest. They are also expensive, neglect the role of community stakeholders, and essentially beg the whole development question in the first place. At some point, the long-term viability of a given project needs to be critically examined. What lasting and truly sustainable development has actually occurred if, for instance, the proper functioning of a solar power system requires a life-long maintenance commitment on the part of its original installer? An appropriate analogy could be that so-called ‘sustainable development’ projects which are not designed or, in practice, able to subsist without continuous external intervention are the moral equivalent of a business trying to stay afloat by purchasing its own inventory.

### *2.3.3 The Bottom Line*

In unfortunately common fashion, humanitarian development projects involving solar technology fail. The specific reasons for failure vary, but it tends to be the case that development organizations neglect to plan for the problems of cost after installation. The knowledge required to sustain a given project is not properly transferred, and community stakeholders are generally left by the wayside. (Unrealistic notions of reliability may also be partly to blame: Solar energy systems are often naively expected to run without maintenance.) As a result, these systems are unintentionally misused, their batteries are overdrawn to the point of depletion, and they eventually stop functioning altogether.

Situations like this are all too common in the aftermath of short-sighted development projects, and must be avoided if such efforts are to be taken seriously. A sustainable project is more than the hip photo-op aesthetics of a solar array in a small African town. True sustainability must consider the economic impact of the introduction of technological infrastructure, and have sustainable financing schemes built in to account for both the costs of maintenance and the training of community stakeholders. Anything less is a waste of time and money.

## 2.4 The Role of Remote Monitoring

The use of such an extensive argument to establish the point that solar technology is emphasized by development organizations and in many cases poorly implemented in practice may seem somewhat extraneous. Additionally, the concepts of sustainability and sustainable development in general might also appear at first glance to be off-topic when considering the core subject matter of an open-source remote monitoring system. In reality this entire context is essential, because the solutions to be proposed here are arguably incoherent without it. A remote monitoring system is *part* of the sustainability of a given project involving solar technology, precisely because it can be of such crucial assistance in the maintenance process (a point which will be explored in greater detail later). The viability of development projects is a function of their sustainability. The fact that the history of humanitarian development is one of mostly failure and disappointment is a crucialpoint to digest in the process of understanding this system. It is impossible to phrase a solution in such a way that properly addresses this context without first understanding the full scope of the issues. Furthermore, the realistic potential of these sorts of projects is often overstated. A sober and well informed approach serves to mitigate this tendency. This project does not purport to be a silver-bullet to solve the issues of solar power system maintenance in Sub-Saharan Africa. It is simply an attempt to discover a small piece of the problem that *may* be addressable through the development of *some* technology—in this case a remote monitoring system.

### *2.4.1 Maintenance and Information Technology*

Development is a difficult process to get rolling in truly sustainable fashion. While in theory, considering the pitfalls of external dependencies, a more grassroots approach may be the preferred strategy, in practice it often makes more sense to try and spur growth through an initial investment, external or otherwise. The experiences of the solar energy dissemination programs in Zambia and Namibia in fact argue this. Given the economic realities of poverty, the only way to leverage the potential of solar energy technologies in underdeveloped communities is through charitable investment. It’s just too expensive otherwise. So, assume such investment exists—because it does. (This fact is agnostic with respect to whether we agree that it *should* be there.) The problem, then, is how to manage costs after installation. It is arguable that if the costs of maintenance can be accounted for in a sustainable way, then use of solar technology can be of enormous economic and social benefit through the income-generating activities it can enable, as well as the benefits it holds for things like education in rural communities.

Maintenance is a fairly well-defined task in the case of solar energy systems. The essential challenge is the proper cycling of batteries based on available sunlight and expected energy demands. As supported by the aforementioned case studies and other literature, the critical variable in the longevity of any solar power system is the degree to which the battery bank is properly cycled. This means that when the battery bank is drawn too low, turn off the load! Power down the inverter! All that this process really requires is the ability to keep track of system state. Any technologies that can obtain and analyze performance data are thus of enormous utility. This is a problem of information—because the easier that system diagnostics are to acquire and distribute the more reliable and robust the maintenance process becomes. And, of course, this is the third premise for the justification for this project.

### *2.4.2 Remote Monitoring*

Enter remote monitoring. The proper maintenance of a solar power system hinges on the degree to which system overseers can monitor the output and performance of the solar panels and the battery bank, and take appropriate action if and when problems occur. Thus, if something were in place to track system state and initiate alerts when necessary, system overseers would arguably have all the inputs they need to do their job. Consider for example the idea of a community training center in rural Namibia that operates at night using power generated from a solar array. When it is sufficiently dark, the lights are turned on, and whatever activities the center is being used for can commence. At some point in the night, the battery bank will likely be drawn down to the low voltage cutoff point beyond which the system should no longer be used. Ideally, a monitoring system would detect this problem, and initiate an alert in some form (a call or text message) to a local technician (or the staff at the center) who will then indicate to the appropriate parties that it is time to conclude the night’s activities. The system is then turned off and the batteries are ready to be recharged the next day.

A sustained responsible cycle of charging and discharging the batteries in this fashion will allow the solar power system to be maximized in its longevity and utility to the community. Furthermore, if some remote logging and analysis functionality has been implemented, system technicians can monitor the performance of the system over time and be able to judge when important adjustments or routine maintenance need to occur. Allowing the critical diagnostic information about a solar power system to be readily obtained and analyzed anywhere at any time would render the quintessential task of maintenance trivial.

This is the fourth premise of this thesis. Since the maintenance of a solar energy system is essentially a problem of information, remote monitoring can supply a solution. Of course, remote monitoring is fundamentally auxiliary—it is only a way to assist system overseers in their existing role and cannot possibly be expected to replace them. Nevertheless, the chances for the long-term successful operation of a solar power system can be greatly improved through the use of remote monitoring because of the flexibility, transparency, and the quality of information it can provide.

## 2.5 An Examination of Existing Remote Monitoring Systems

At this point the fundamental argument for the use of remote monitoring in the context of development projects in Sub-Saharan Africa has been rigorously established. Unfortunately, this justification is not sufficient to explain why remote monitoring requires an open-source solution. There are existing remote monitoring systems on the market, so why re-implement this functionality?

The problem with existing solar monitoring systems is that they are limited in their application, are expensive, and in most cases require paying service fees to a third party above and beyond the cost of basic communication. In places where solar energy systems are employed as a replacement for a lack of electrical grid infrastructure, this cost may be so extraordinary as to lead to the abandonment of the idea of remote monitoring altogether (the more likely scenario being that it is never introduced in the first place). Thus, the reality of expensive and proprietary remote monitoring technologies holds hostage the viability of renewable energy systems in developing countries. In order to be practical, the cost of a monitoring system needs to be tailored to the economic reality of the environment in which it is implemented.

### *2.5.1 How Remote Monitoring Works*

Effectively exposing the problems with existing solar monitoring systems requires backtracking to a more fundamental discussion of how these systems work in the first place. To begin, solar power systems tend to come in two flavors–remote and grid-tied. Remote systems are not connected to the electrical grid and serve as a primary power source. Grid-tied systems are integrated with the electrical grid and tend to serve as an auxiliary power source. The function of a remote system is to charge a battery bank that is tied to an inverter, which produces generally consumable alternating-current (AC) power. The function of a grid-tied system is to feed directly to an inverter and supply power while the sun is shining, deferring to the grid when it is cloudy or dark. The system proposed and implemented here is developed with a remote system in mind.

Remote solar power systems use devices called charge controllers to apply charging algorithms to banks of deep-cycle batteries. Controllers are essential because using solar panels to charge batteries is not a trivial task; a delicate balance must be struck between the need for batteries to be charged using well-defined and consistent charging cycles and the fact that the output of solar panels can be inconsistent and erratic depending on the weather. The primary function of a controller is to prevent the battery from being overcharged by the solar array. Nowadays most charge controllers are equipped with microprocessors that maintain historical data about the amount of power produced by a system. The diagram on the next page is helpful in understanding the high-level components involved in a common solar power system.

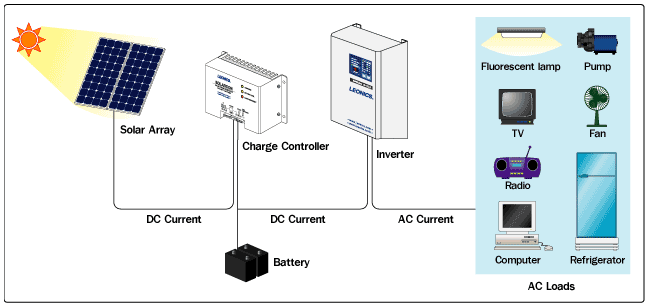


Fig 1: The Basic Design of a Solar Power System (Source: Leonics Co. LTD, 2009)

Monitoring is conducted by interrogating a charge controller about the performance of a power system, and transmitting that data to a remote location or specific person. A cellular modem or other transmission device is generally the vehicle for this transmission. Many solar controllers have serial ports built into them that can be polled for data about a given system using some transmission protocol. Some controllers use open protocols to do this, others do not. A useful diagram to understand the high level structure of a remote monitoring system is shown below.



Fig 2: The Morningstar TriStar Web View remote monitoring system (Source: Morningstar Corporation)

For clarity’s sake, the diagram in Fig 2 is a diagram of an actual industry product from Morningstar Solar. The TriStar device is the solar controller. The next section discusses this and other systems in greater detail.

*2.5.2 Existing Monitoring Systems*

The industry leading solar monitoring system, according to Harald Kegelmann, CEO of Advanced Solar Technologies, Inc., a Gainesville-based solar energy installation company, is the Sunny Webbox, a remote monitoring device offered by SMA Solar Technology. SMA is a German solar energy equipment supplier. The Sunny Webbox itself is essentially a glorified modem that plugs into a grid-tied inverter and transmits data about a given solar power system directly via the Internet. SMA provides the hosting for the Sunny Webbox’s web interface. Unfortunately, the communication protocol between the Sunny Webbox and an actual SMA inverter is not well documented or supported by SMA so it is difficult to program against, for the obvious reason that SMA prefers its customers to purchase SMA monitoring services. Furthermore, the Sunny Webbox requires wired Ethernet in order to remotely transmit data, which is an obviously crippling dependency if we intend to monitor devices operating in truly remote environments or in places without adequate internet infrastructure. Furthermore, the price tag of the Sunny Webbox device is on the order of $690 US. As it turns out, this is actually a fairly average price for such technologies.

Another industry-leading system is implemented by Fat Spaniel, a company that provides high quality web-based solar monitoring for a monthly fee (this is of course not including the hardware which must be purchased to interface with the solar controller). This service is slightly more robust than the service offered by SMA because Fat Spaniel employs cellular modems to remotely transmit data from a given solar controller. Furthermore, Fat Spaniel also recently began offering an open platform to expose their data to outside applications. Of course, this data is still only available for a monthly service charge of roughly $50. A range of services are available, and this fee can wind up being as low as $20 per month or as high as $120, depending on the options desired. One solar energy company that offers a monitoring service through Fat Spaniel is Morningstar Solar.

Morningstar Solar sets itself apart from SMA in one particular respect because they use the open Modicon Modbus transmission protocol for Programmable Logic Controller (PLC) devices to allow external applications to interrogate their controllers. They provide the specification for their implementation of the protocol and thus allow other implementing technologies to be used with their controllers relatively easily. It is for this reason that this project is implemented using a Morningstar Solar TriStar-45 controller as an exemplar solar controller device. The Fat Spaniel hardware that is compatible with Morningstar controllers is listed at affordable-solar.com for the price of $1375. While Fat Spaniel services are more robust than SMAs, costs on this order of magnitude are a deal-breaker for communities in Sub-Saharan Africa that might consider the use of remote monitoring to assist in the maintenance of their solar power systems.

Another monitoring service offered by Draker Laboratories, which specialized in commercial-scale remote monitoring services. While Draker services are of high quality and utility, their remote monitoring services are on a scale that is simply overkill for the vast majority of small solar home systems.

Outback Power is another solar energy technology company that produces excellent Maximum Power-Point Tracking (MPPT) controllers; however, they do not offer Internet-enabled remote monitoring services of any kind. This might not be an issue, necessarily, if an open protocol were defined to interrogate their controllers using a cellular modem or other such remote monitoring device. However, the protocol used by their controllers to communicate with wired external monitoring LCD devices is explicitly described in their documentation as proprietary.

This overview of some of the industry-leading solar monitoring technologies is intended to establish the fifth premise for the justification of the project; that existing remote monitoring systems are expensive, limited in their application, and require paying proprietary service fees to third parties. When viewed through the lens of the economic realities in Sub-Saharan Africa, even if remote monitoring hardware were provided by an international development organization as part of a solar energy dissemination program, even the most modest servicing fees and associated costs would be too great.

### *2.5.3 How This Project Departs From Existing Monitoring Systems*

The final premise required for the justification of this project is established editorially. Existing monitoring systems do not meet or consider the needs of solar power applications in the developing world. This is not the fault of the corporations that implement them, of course. The reality is that remote monitoring has never been phrased as a problem in the context of the viability of solar power systems in rural communities in Sub-Saharan Africa. The contributing research to this thesis revealed no accounts of remote monitoring systems even being considered by development organizations undertaking solar energy dissemination projects. If a system were to be designed to work in this context, it would almost by definition have to be open-source. No proprietary servicing scheme through an international third party or major monitoring company could ever hope to be cheap enough. Furthermore, most of the remote monitoring systems on the market are overkill. The maintenance of a remote solar power system simply does not require such advanced technology.

This project represents a significant departure from existing solar monitoring technologies because it is specifically intended to be open-source in every aspect outside of the actual solar power system itself. Currently there are no existing systems with similar intentions to what is being proposed by this project—indeed, if the string “open source solar remote monitoring” is typed into Google and searched, this project’s development page is the first result.

At this point, this thesis has established the necessary premises to justify the implementation of an open-source monitoring system for remote solar power systems. The following sections are a description of such an implementation.

# Requirements and Implementation

If we accept the argument that maintaining a solar power system is essentially a challenge of obtaining critical information about the system and taking appropriate action, we can propose a solution in the form of a remote monitoring system. However, there are more concerns than just this. One of the greatest problems with remote monitoring, again, is its cost. So, a system that is intended to serve the purpose of remote monitoring in developing countries and rural environments must be inexpensive in addition to being effective. The most important factor to minimize is the cost after installation.

The up-front cost of a remote monitoring system is of course the hardware required to conduct the monitoring. After this cost is absorbed the problem becomes the cost of using the air waves to transmit data wirelessly. In the case of monitoring services, there is also a great deal of overhead that is built into servicing fees. This cost can be completely eliminated if a system is designed independently of a servicing company. While the expertise required in the maintenance solar power system is of course of some value, the expected service charges of any proprietary monitoring system are a deal-breaker in the context of developing countries. Of course, without resorting to illegal measures, it is practically impossible to transmit data over long distances wirelessly, so some cost is to be expected. This can be minimized of course, and this shall be discussed further in this report.

## 3.1 Solution Statement

The purpose of this project is to design and implement an open-source monitoring system for remote solar energy power systems that can deliver useful diagnostic information to system overseers.

This system is divided into two different parts. The first is a hardware-centric component that interfaces with a solar charge controller to determine diagnostic information about a power system. This component will process obtained data and transmit it via a telephony communication protocol to a server or, if necessary, a specific person.

The second component of the system is the recipient software on the other end of this transfer. This software shall store historical data about the solar system and provide a web interface through which long term statistics can be determined and effective monitoring can be conducted.

### *3.1.1 High Level Overview of the System: The Hardware Component*

The first part of this system is a hardware device that interfaces with a solar controller, polls it for information, and relays that information remotely to an appropriate party. This hardware component is designed with certain constraints in mind. First, it must not rely on customized hardware, or, if specific hardware must be utilized, it must be either open-source, or utilized in such a way that is agnostic with respect to any proprietary design detail. The solar controller itself is not considered to be a part of this specification because it can operate independently of any monitoring activity and is a general requirement of any functional solar power system.

#### 3.1.1.1 The Morningstar TS-45 Controller

The solar controller that this project is designed to be compatible with (at least as a proof of concept) is the Morningstar TriStar-45 solar controller. This is on account of several factors, including personal experience working with Morningstar solar controllers, the availability Morningstar controllers internationally, and the fact that applications can be easily developed to work with Morningstar controllers because they use the open Modbus hardware communication protocol.



Fig 3: The TriStar-45 Solar Controller (Source: Morningstar Corporation)

The Modicon Modbus protocol reference guide is freely available online, and also includes sample code for more tedious implementation details such as the creation of a working Cyclic Redundancy Check (CRC) function. This specification was utilized to implement the software required to interrogate the TriStar-45 controller.

Morningstar offers all of the required documentation to develop applications in conjunction with their controllers online. The “TriStar Applications Guide”, for instance, describes sample configurations for data acquisition and remote monitoring of solar power systems. This guide also directs the user towards further documentation regarding the monitoring service that Morningstar offers through Fat Spaniel.

The TriStar-45 has a serial RS-232 port built in which enables external devices to communicate with it. In a remote monitoring system, this is used as the interface between the data transmission hardware and the solar power system itself. The figure below shows the hardware interface of the TriStar-45. Item number 2 is the serial port.



Fig 4: The Hardware Interface of the TriStar-45 (Source: Morningstar Corporation)

#### 3.1.1.2 Arduino and Freeduino Microprocessors

The other major technology that is utilized in this project is the Arduino electronics prototyping platform. Arduino is an open-source hardware platform intended mostly for hobbyists and casual hardware enthusiasts. Boards come in ranges of power and potential, and can be built by hand or purchased preassembled from organizations such as SparkFun. All hardware part listings, board schematics, and documentation required to build Arduino clones can be found and downloaded online. Guides can also be found to etch the Arduino PCB board by hand and solder it together. The software environment required to write and upload programs to Arduino boards is also freely available and completely open-source. Arduino boards and software are released under Creative Commons Attribution Share-Alike Licenses.

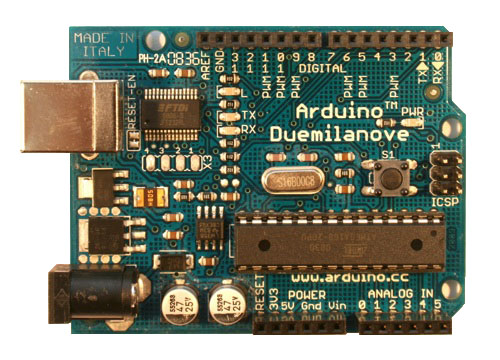


Fig 5: The Arduino Duemilanove (Decimilia schematic)

The Arduino hardware environment is an ideal platform for a project like this because it allows the required hardware to be reproduced in any context where the parts can be found. The availability of parts is an obvious concern, but this is vastly preferable in the context of this project to purchasing a finished product from a specific company. In an effort to demonstrate this possibility, this project has opts to use a Freeduino board instead of an Arduino board. Freeduino is an open-source clone Arduino clone that can be purchased from hobbyist electronics websites as an unassembled bag of parts and a cut PCB board. (It also costs a fraction of the price of a preassembled Arduino board.) As part of the documentation for this project, an assembly guide for this board is provided online.

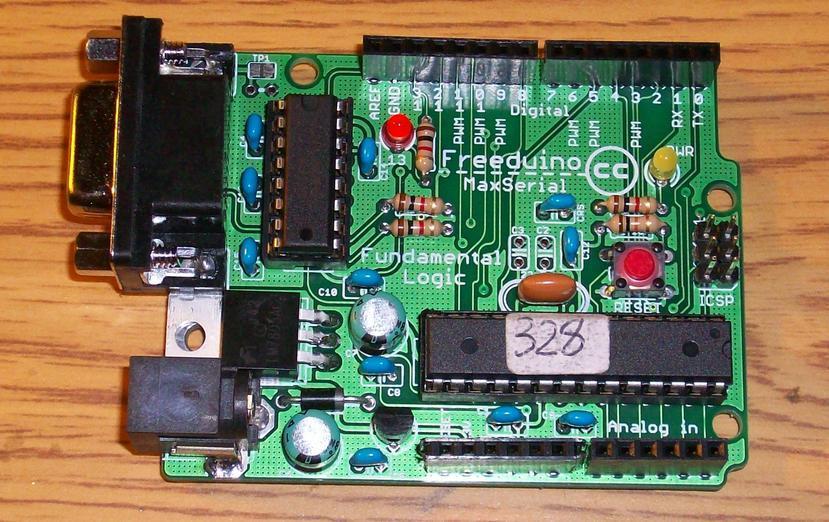


Fig 5: A Freeduino MaxSerial Arduino Clone

This project uses the Freeduino MaxSerial, which has an RS-232 port built in. This is required to interface with the Morningstar Solar controller, which allows external devices to interrogate it through an RS-232 9-pin serial port. (Most Arduino boards now use a USB port for serial communication, so the Freeduino MaxSerial is actually an implementation of a now-obsolete Arduino specification.) The Freeduino board is based on the Arduino Decimilia specification, which uses an ATMega328 16 MHz microprocessor, and has 14 digital I/O pins, 5 analog input pins, and several voltage outputs for external circuitry.

#### 3.1.1.3 The Motorola W260g

The last piece of hardware utilized in this project is a Motorola W260g cellular phone, which for the purposes of this project has been engineered into a data transmission device. This is inexpensive disposable cell phone model generally sold by Tracfone, a pay-as-you-go cellular service company. In this project, the W260g serves as a replacement for an expensive cellular modem. As was the case in every example of existing remote monitoring systems, an expensive and overblown cellular modem is always employed as the actual data transmission device. Considering the fact that these devices are on the order of $600-$800, the exploration of the potential of disposable cellular phones is a worthwhile endeavor. The W260g is available for $14-$15 dollars. While the use of any given hardware generally couples a project to the nuances of a particular device, it is arguable that no part of the hardware design in this project is dependent on the specific design of the Motorola W260g. This will be explained in greater detail later.



Fig 6: The Motorola W260g (Source: Amazon.com)

#### 3.1.1.3 How These Parts Fit Together

The Freeduino MaxSerial is the pivotal component of the hardware component of this system. The MaxSerial uses the RS-232 serial port on the TriStar-45 to obtain critical diagnostic information about the performance of the solar panels and batteries, and then manipulates a circuit attached to the cell phone to transmit that data over the airwaves as a string of DTMF tones.

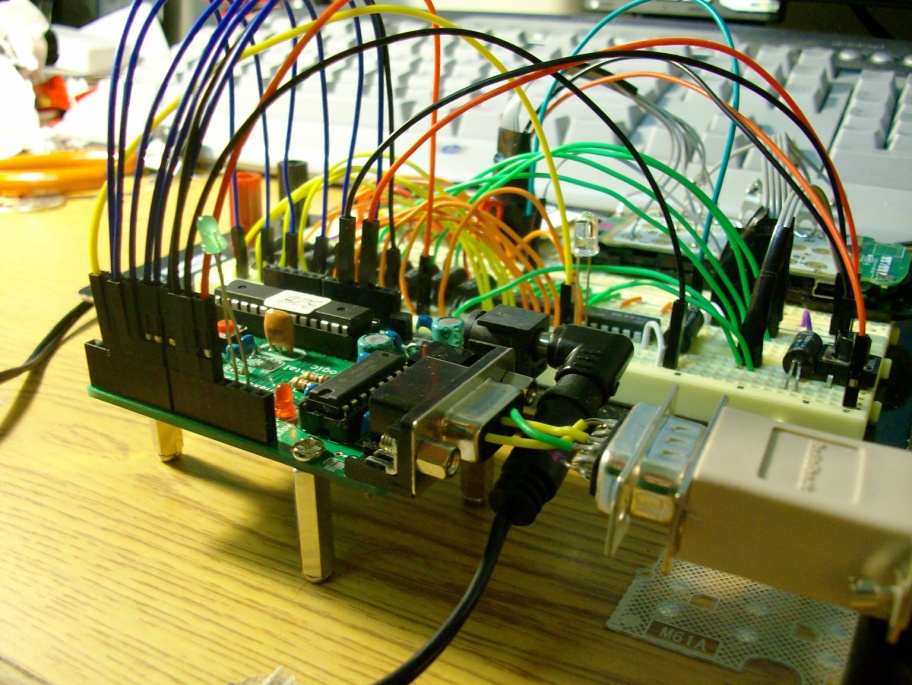


Fig 7: The Hardware Component

### *3.1.2 High Level Overview of the System: The Software Component*

1. While the proper maintenance of solar power systems requires regular to intermittent attention on the part of trained individuals, a significant portion of the maintenance process is an information technology problem.
2. An information technology solution in the form of a remote monitoring system can serve a critical role in providing system overseers with the information required to maintain solar power systems.
3. Existing solar remote monitoring systems are expensive, limited in their application, and proprietary for the most part.
4. Such a system should be available as an open-source technology because of the economic realities of poverty and underdevelopment in Sub-Saharan Africa.

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1.) “How is the school in Gambia doing?”

2.) “How are you doing in school?”

I hope this project serves, in some way, as an answer to both of these questions.