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Development of Smart Grid System for Small Research Complex in Texas. Part 1: Yearly Demand/Supply Profile and Percentage Contribution of Renewables

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Abstract— *This project attempts to develop a smart grid system at the Agricultural Engineering Research Laboratory (AERL) of Texas A&M University. The laboratory housed three building complexes as follows: (a) research lab offices (Hobgood building), (b) power and machinery laboratories (P&M building), and (c) machine shop (BAEN shop). Part 1 of the study is the establishment and evaluation of overall load demand and supply by renewables.*

The Bioenergy Testing and Analysis Laboratory (Beta Lab) has developed a renewable energy power generation system at the complex that is being net metered to the building. The overall goal is to make this complex independent of the grid via the use of 100% renewable power. Currently installed are 3kW solar pV system, 1 kW wind power, 20 kW biodiesel plant and the 30 kW gasification for power facility.

It was discovered that the overall complex only uses an average of 33.6 kW of power each year and hence, the demonstration for 100% renewable power was envisioned. This initial write up addresses the demand and supply profile to evaluate what improvements are needed to satisfy 100% use of renewable power in the near future and demonstrate smart or micro-grid systems.

Initial study showed that while the installed renewable power (54 kW) is much greater than the average power demand (33.6 kW), there are numerous times in the year where peak power exceeds the total installed capacity. Hence, improvements must be made to address the deficit in power needs during peak hours. The initial study recommended the installation of 4-5 kW of renewable power from either solar or wind power to serve as parasitic load. The peak load happens during work hours where sun and wind power are usually available. In addition, an additional 10 kW backup battery storage system is necessary since most peak demands are small in nature and would occur only for a few hours.

Keywords— *Smart grid; microgrid; renewable power; grid-tie system; net metering; peak power demand.*

I. INTRODUCTION

Numerous countries around the globe are increasing their renewable energy power mix primarily due to climate change and carbon credits. For example, the target of European Union countries is to use about 20% renewable power by 2020 with Denmark leading the way at above 50% from wind power [1]. Unfortunately, there is unpredictability in many renewables and they are not usually available when it is needed, especially during peak power. The use of renewable energy is still affected by initial capital costs and hence, reliability and efficiency of operation must be addressed carefully to improve economic and environmental welfare. This is where smart grid systems are most applicable [2].

Smart grids interconnect both information and communication technology (ICT) with the power network [3]. The goal of this project is to convert the existing conventional passive network at the Agricultural Engineering Research Lab (AERL) at Texas A&M University (TAMU) into an active network with two-way communication capability. This conversion will help students and research personnel learns all rudiments of micro-grid and smart-grid systems and learn to apply on bigger more complicated setup.

The AERL. TAMU through the BioEnergy Testing and Analysis Lab (Beta Lab) has already installed renewable power systems from solar, wind and biomass power (biodiesel and gasification systems). It is currently being net metered to the grid. The overall goal is to provide 100% renewable power in this complex, via smart or micro-grid system through careful step-by-step improvements. Extensive research is necessary to convert the present setup into sophisticated smart grid systems and this initial report simply evaluate the demand and supply profile throughout the year and evaluate improvements that should be implemented for active micro-grid system.

II. DESCRIPTION OF PROJECT SITE

The plan view of the project site is shown in Figure 1. There are three main building as follows (lettered in Fig. 1):

a. The Price Hobgod Office Building (Hobgood)
b. The Power & Machinery Building (P&M), and
c. The BAEN Shop

At present there is only one active power control for the complex found on the 500 kW net metering node on the southwest portion of the Hobgood building. In the future these three building will be treated as individual micro grid system with defined load profile. At present there is only one active power measuring point (at the net metering location in Hobgood building south-end). The average power demand for the complex each year is about 33.6 kW. The peak load is around 70 kW and usually occurs during the Spring and Fall Semester when agricultural engineering and machinery management students have shop and power and machinery classes.

The renewable power currently installed are as follows (numbered in Fig. 1):

1. 3 kW solar pV system
2. 1 kW wind power system
3. 20 kW biodiesel power plant, and
4. 30 kW fluidized bed gasification plant

Detailed description of these renewable power system and their operation is described in detail in the next section. The total installed capacity is approximately 54 kW but the average power production in a year is a little over 50 kW. While it would appear that the installed renewable power is much greater than the demand, there are actually numerous times within the year where the peak power exceeds the supply. Hence, this paper carefully evaluated the day-to-day power profile and comparing electrical demand and available renewable power.

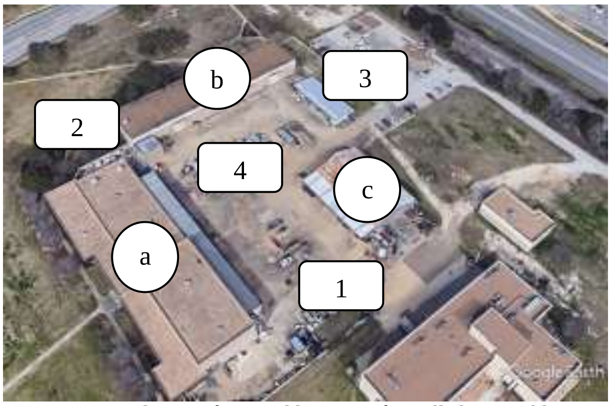

Fig. 1. Aerial view of site and location of installed renewables

III. Yearly Power Demand

Figure 2 shows a year round demand for power in the AERL complex in 2017. The average power demand is 33.6 kW and varies from a low near 20 kW to a high of 70 kW. Since the renewable power is approximately a little over 50 kW, one will clearly see in the graph that there are several months where the power requirement exceeds the supply from renewables. If one will draw a line on the 50 kW load, one will be able to observe that there are days in the months of January, February and March (n=1 to 90) where the demand exceeds the supply. There is also a day or two in October and November (days 304 to 334) where this is exceeded as well. The summer months of May, June, July and August (n = 151 to 243) shows intermittent exceedances.

These analysis showed that there is problem with the current level of demand and supply from renewables. Simple averaging would not solve the issue but the development of a smart grid system in this complex will be a good learning tool for students and researchers. Hence, the BioEnergy Testing and Analysis Laboratory (Beta Lab, the operator of the renewable power facilities) has made a proposal to the Texas A&M University Utilities Energy Services (UES) to make this complex independent of the grid. The UES has agreed on this plan and is now installing a net metering system to interconnect all renewable power to the grid and begin the conversion of this complex from a passive power control system to an active micro-grid or smart grid system.

The UES then asked a thorough evaluation of the power demand and supply and provide directions for improvements over the years as well as contingency measures to demonstrate smart grid setup.

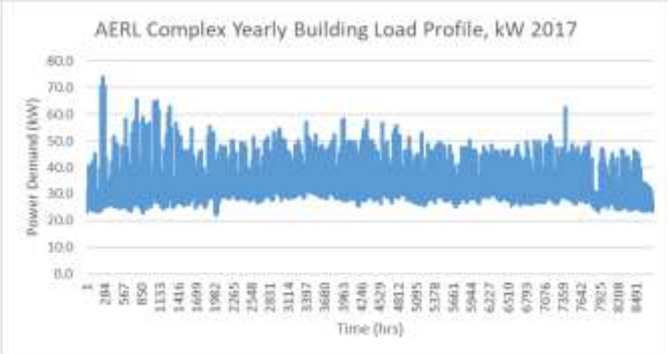

Fig. 2. AERL complex yearly building load profile, kW (2017)

IV. Installed Renewables

There are four (4) renewable power systems already installed in this complex and each system will be discussed in this section.

A. *System 1: 3 kW Solar pV system*

The 3 kW solar pV system comprised of 52 units of CdTe advanced pV system and currently supplying power to a small greenhouse for a separate Water-Energy-Food (WEF) Nexus project. CdTe systems are one of the best known semi-conductors [4]. The system was assembled by student groups as part of their renewable power course. Each year students conduct experiments on how to improve the overall efficiency of the system.

The system shown in Figure 3 is divided into 3-1 kW setup and capable of being moved perpendicular to the sun or on two axes to increase the amount of solar energy received and thereby the overall efficiency.

Fig. 3. Photo of the new CdTe 3 kW solar pV system at AERL complex

One such study is the evaluation of overall power output and compare that will additional power needs when the whole pV system is to track the sun. The results of such study will be reported on a separate paper. At present each system is fixed at an angle equal to the latitude of the place (30^{o}N). The reported overall conversion efficiency of these advanced pV system was 22.1% [5].

Previous study at AERL [6] for similar advanced system using GaAs showed overall efficiency of 18.36%. Hence, the currently installed system is much more efficient than Beta Lab's old pV system.

B. System 2: 1 kW Wind Power

The 1 kW wind power system (Bergey Windpower, OK) is located at the P&M building. The unit is not yet connected to the grid and has its own battery storage system that is supplying power to some student projects during the renewable power class. The unit will soon be net-metered to the grid.

Students are using the setup to make an estimate of the potential power from the wind at various other sites and at varied installed heights. Three year running data showed that power may be increased significantly of the height is further increased.

The yearly average power output is very close to 1 kW. A meteorological station installed close to the wind power generation system measures wind speed at the same height and hence students can estimate real-time conversion efficiency through the data logging system that also measures power output of the wind machine.

C. System 3: 20 kW Biodiesel Plant

The 20 kW biodiesel plant is located on the north-east side of the complex between the P&M building and the shop. The system is strategically placed at this site for future supply of power to the shop and P&M building.

This power generation system is actually a project of a volunteer student groups whereby waste oil from nearby fast food chains are collected each week and students make their own biodiesel. The Beta Lab has a 100 liter [25 gallon] biodiesel production facility [7]. Students are using this facility to make their own fuel for their diesel trucks. If operated continuously, one may be able to generate at least 400 liters [100 gallons] of biodiesel each day, enough to power the plant continuously for 24 hours. The students will only have to spend their labor and catalysts for the process.

Separate research studies are made by student groups on the glycerin by-product. Some student have made their thesis by producing biogas (CH_4 and CO_2) through anaerobic digestion via co-digestion with other biomass wastes. The unit is also not yet net metered to the grid. Studies are currently being developed by students to improve the efficiency of operation and develop simple economic analysis of the system. The student groups are hoping that when the unit is final net metered to the grid and generating continuous power, the university will provide them the avoided cost as part of their fund raising campaign for their club.

D. System 4: Biomass Gasification for Power

The 30 kW biomass gasification power plant is a long-term project of the Beta Lab [8]. A mobile biomass gasification system with a maximum power output between 200-400 kW was envisioned for demonstration purpose. The UES was interested to demonstrate net metering such that other biomass wastes from campus may be converted into electrical power and the power output also net metered. There are logistic issues running this power output. At its maximum power output, it would require between 2-4 tons per day of dried biomass for continuous operation. The university agricultural lands have enough biomass for the continuous supply for this facility. However, at present it is just used to demonstrate power generation from various biomass residues available at the research station.

The system has a dedicated gas cleanup system to demonstrate power and instead of maximizing power output, a small 30 kW power generation system was installed [9]. Hence, during gasification operation, only part of the synthesis gas is diverted to the gasification power plant [10]. Figure 4 shows the complete system during testing. Note the load bank on the foreground. The system is also not yet metered and hence each test episode would require the rental of the load bank. The UES agreed to net meter the whole system to the grid such that rental of load bank will not be necessary.

Fig. 4. The mobile gasifier power testing showing load bank on the foreground

V. DEMAND/SUPPLY PLOTS

Figure 5 shows the typical daily demand supply plot showing the power demand at the complex and the distribution where the power is coming from. For this particular month in January (hour 1 to hour 48), all the demand power were satisfied by renewables and there is excess power from renewables that is net metered to the grid. The average power during non-working hours is around 25 kW and would usually peak during work hours. For this particular demand plot, the peak load is only around 40 kW which is much lower than the sum of all the renewable power output.

Typical operation of the renewables system showed that the 3 kW solar power is contributing its maximum power output as well as the 1 kW wind power system. The 20 kW biodiesel plant will have to operate 24 hours to make the system independent of the grid. The biomass gasification power system is only used during times when all of these three power sources are not enough.

There is approximately 30 minute lag time for the biomass gasification power to be active power source and hence during this period a battery backup system must handle the load until the gasification system is on stream. In the future, when a smart grid system is installed, the artificial intelligence of the smart grid system should be able to make projection of the time that the gasification power is needed and hence, minimize the use of back up battery system.

The location of the mobile gasification system is in the middle of the complex (see Fig. 1) and hence should be able to provide power to any major building in the AERL complex during active smart-grid operation.

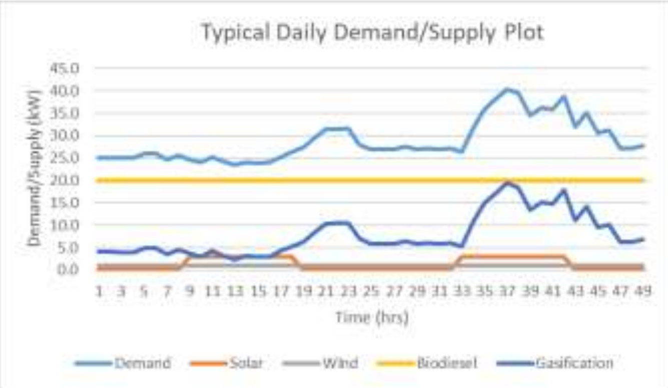

Fig. 5. Typical daily demand/supply chart.

VI. PERCENTAGE CONTRIBUTION OF RENEWABLES

Figure 6 shows the percentage contribution of the renewables through a year of operation. The largest contribution comes from the operation of the biodiesel power plant. It provides about 67% of the total load year round. This was followed by the gasification power at 26%. The solar and wind power only contributed 4% and 3% of electrical power, respectively.

Hence, there is a need to expand the contribution of the solar and wind power systems. It was envisioned that the wind power will be lined up along the side of P&M building while the solar system will be installed on the roof of the shop building. Hence, proposals are being written to increase the solar and wind power installed capacity. The size of which will depend on the results of this study.

The average power output of the biomass gasification system is only 13 kW. Hence, it seems obvious that the whole system should be able to supply the needed power in this facility year round. However, close and comprehensive analysis showed that there are numerous times in the year where the peak load exceeds the supply of power from renewables and this must be addressed quickly to attain the goal of 100% independence from the grid. Unfortunately, one will not be able to determine these times of the year when additional backup power is needed unless the whole system will be converted into an active or smart grid system.

The next section evaluated several improvements that needed to be implemented to achieve the goals of the project.

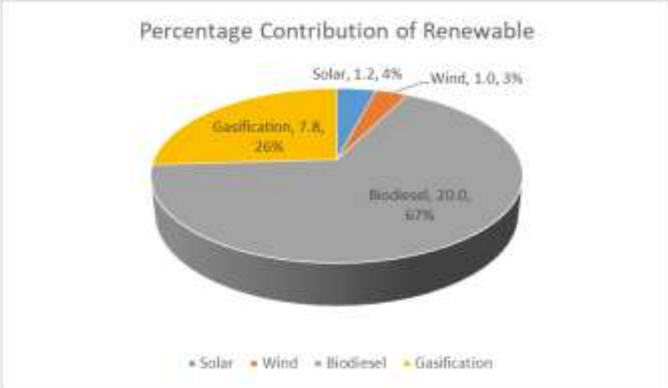

Fig. 6. Current percentage contribution of renewables.

VII. FUTURE SYSTEM IMPROVEMENT

The yearly simulation studies showed that there are numerous times within the year where there is deficit in power supply. The total installed capacity from renewables is 54 kW and the average power demand of the complex is only 33.6 kW. However, there are instances when the peak power is more than the installed renewable capacity. This is shown in Figure 7.

The months from January to March, and May to August shows peak power exceeding installed capacity. There are also peak power needs during the months of October and November. Hence, these are the critical times when the complex would need grid power. Surprisingly, the months of April, September and December are months where the renewables are satisfying the demand of the facility. The actual data and over power needs are summarized in Table I.

A monthly average power needs of 26.2 kW is needed to operate for around 7.2 hrs in a month. The difference above installed capacity is around 3.7 kW. This implies that an additional installed capacity of 4-5 kW is needed year round or a battery backup system must be installed to address this deficit.

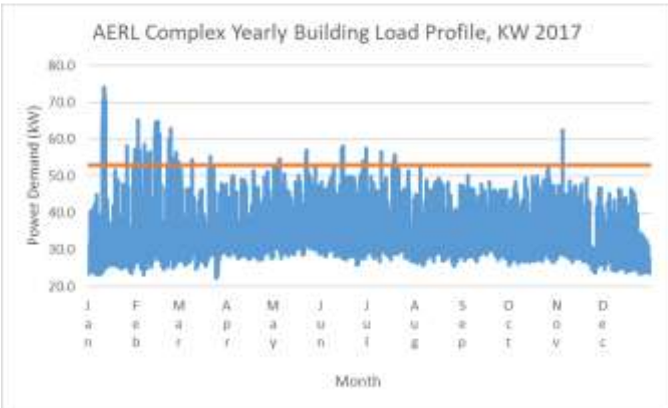

Fig. 7. Months within the year where peak load power is needed.

Some monthly differences are quite small. For example, during the months of August, October and November, only an average of a little over an hour of excess backup power operation is needed having a power capacity of 4.8 kW.

Hence, the justification to add 4 or 5 kW of parasitic load from either solar or wind including additional battery backup system. Note the deficit usually happens during the day where solar and wind energy are usually available. The highest peak demand is approximately 15 kW. Thus, adding 4-5 kW power will still not satisfy the peak load issue. Additional battery backup system is very necessary with a reserve capacity of at least 10 kW.

TABLE I. Average peak power, number of hours and excess power needs during peaks demands

Months	Average Power (kW)	Time (hrs)	Peak Demand (kW)
January	44.0	7	14
February	35.0	45	5
March	31.6	6	1.6
April	0	0	0
May	32.3	10	2.3
June	34.3	6	4.3
July	32.7	8	2.7
August	31.9	1	1.9
September	0	0	0
October	30.8	2	0.8
November	41.6	1	11.6
December	0	0	0
Average	26.2	7.2	3.7

VIII. Conclusion

This report showed that while the total installed renewables capacity of 54 kW at the AERL complex exceeds the average power demand of 33.6 kW, there are numerous instances within the year that there is lack of peak power and the facility will have to resort to grid connection. Hence, the goal of 100% renewable power has not been achieved for this year's initial study. Some improvements must be made such as installation of reserve battery capacity or increase the parasitic load power supply from the other renewables.

Among the renewables installed, increasing the installed capacity for wind and solar energy must be made in the next coming year. Currently, their combined contribution to the electrical power demand is only around 1.2 and 1.0 kW respectively, or a mere 7% of the total supply from renewables. The initial study showed that at least 4 kW of power is needed from these systems while providing 15 kW of battery backup storage system to operate during peak loads.

Note that the 20 kW biodiesel plant will have to operate year round as a primary supplier of electrical power in this complex. This power plant supplies about 67% of the total power demand. This will put a lot of strain in the student groups operating and maintaining this power plant, primarily fueled by used oil from nearby fast food chains.

The gasification power may have to be operated more to reduce the pressure on the biodiesel power plant but the main constraint for this power option is the continuous availability of waste biomass for operation. The average contribution of gasification power throughout the year is only 13 kW, a mere 43% of its capacity.

In the next series of reports, we will present several scenarios where the complex can be 100% independent of the grid through the installation of reserve battery capacity as well as the increase in the contribution from solar, wind and other renewable power.

Acknowledgment

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