Modular AC Coupled Hybrid Power Systems for the Emerging GHG Mitigation Products Market

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Abstract—Bioenergy systems particularly Waste to Energy (WTE) systems are increasingly gaining prominence. Market for modular Hybrid Energy Systems (HES) combining renewable energy sources including WTEs is potentially large. Novel configuration of AC coupling for HES is discussed. Emerging opportunities for market development of Hybrid Energy Systems under Green House Gas Mitigation Initiatives particularly Kyoto Flexibility Mechanisms is analysed. [1]

1. Introduction

Grid connections were regularly established in the past even if economically not viable primarily motivated by political priorities and lack of alternatives. A World Bank study that included a variety of countries in the Asian and Latin American region concluded an average $10000 per kilometer was being spent on grid extension [1]. Meeting the broad development needs in these nations places numerous competing demands on limited financial resources. Because electrification is just one of these demands, it is even more important that alternative approaches are researched and validated for efficient use of resources for sustainable energy supply. Hybrid energy supply offers a promising alternative in today's liberalized electricity market. A combination of renewable energy sources, such as photovoltaic arrays, biogas generators or wind turbines, with engine-driven generators and battery storage are generally classified as hybrid energy systems (HES). Potential market for hybrid systems is considered to be huge. Annual sales for small powered (<50 KWe) diesel gensets is in GWe ranges with financial volumes touching US$2 billion[2]. The market for pumping is five times larger; Far East and Near Eastern countries dominate the scene. However self sustaining commercial markets for hybrid systems is yet to emerge to justify the potential. Given the marginal market, currently technology development to a large extent relies on research institutes and small and medium enterprises. Innovators have to contribute heavily to initiatives to open new market with active industry participation.

Applications of hybrid energy systems range from small power supplies for remote households, providing electricity for lighting and other essential electrical appliances, to village electrification for communities[3].However, so far the most common of all applications of HES has been that of diesel generator augmentation, where the renewable energy source and the battery bank are sized to reduce the run-time of the engine-driven generator. These systems provide sufficient storage to allow the load to be shifted, therefore ensuring that the generator is always substantially loaded. Pereira listed the most relevant hybrid systems installed around the world in the last decade [4]. Wind systems dominate with Photovoltaic (PV) systems chosen for a few installations. Based on US Department of Energy program results, Burch presented a hybrid technology matrix[5]. This included a comprehensive listing of renewable energy sources that could be combined for a distributed hybrid energy system, rating the status of each combination as commercial, under R&D or as plausible. A number of new combinations are emerging, of particular promise is the combination of bioenergy sources. There have been significant developments in Europe too suggesting the future for bioenergy supply is bright. International Energy Agency (IEA) has set up IEA Bioenergy. 'Task 24' under this (Energy from Biological conversion of Organic Waste) reports there is a rapid increase in the number of power plants around the world to generate biogas by Anaerobic Digestion of Municipal Solid Waste. Annual installed capacity exceeded five million tones with a potential to generate about 600 MWe of electricity by 2001[6]. 'Energy21', the Danish Government's Action Plan for Energy Supply Scenario in that country by 2021 envisages nearly half of the total annual energy requirements are met from bioenergy sources with significant contribution from energy from waste[7].In comparison Wind energy source is expected to contribute to about one fourth of the requirement in the country which pioneered the development of wind energy harnessing with some excellent policy initiatives at an early stage. We look at technical aspects as well as market development issues surrounding energy generation from waste (especially municipal solid waste) particularly looking at the existing barriers and possible strategies to overcome them in the context of emerging opportunities under Kyoto Flexibility Mechanisms. A novel system configuration that particularly

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suits hybridizing waste generated energy with other renewable energy sources is discussed. A possible scenario for waste generated energy in the city of Bangalore to address multiple problems of solid waste disposal, energy supply and greenhouse gas mitigation is presented.

2. SYSTEM CONFIGURATIONS

Hybrid systems can be classified according to their configuration as series or parallel. In the conventional series hybrid systems all power generators feed DC power into a battery. Each component has therefore to be equipped with an individual charge controller and in the case of a diesel generator with a rectifier. For most systems a large fraction of the generated energy is passed through the battery, resulting in increased cycling of the battery bank and reduced system efficiency. Existing systems of this kind generally operate at battery voltages between 24V to 120V volts. It is obvious that in this scheme, the use of standardized components becomes impossible and every solution has to be engineered individually increasing the cost of the system.

The parallel hybrid system can be further classified as DC coupling and AC coupling. In both schemes, a bidirectional inverter is used to link between the battery and an AC source typically the output of a diesel generator. In Fig 1, the renewable energy sources are coupled on the DC side which results in 'custom' system solutions for individual supply

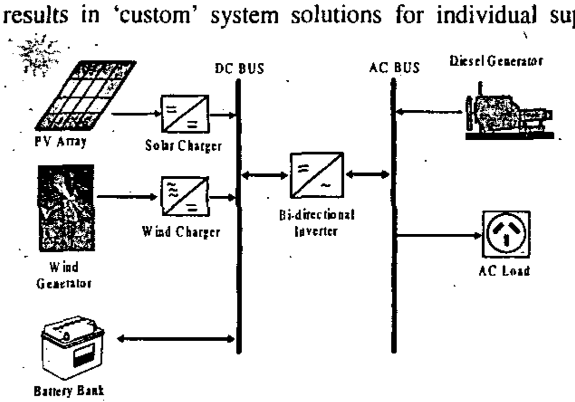


Figure 1. DC integration of sources for Hybrid Systems

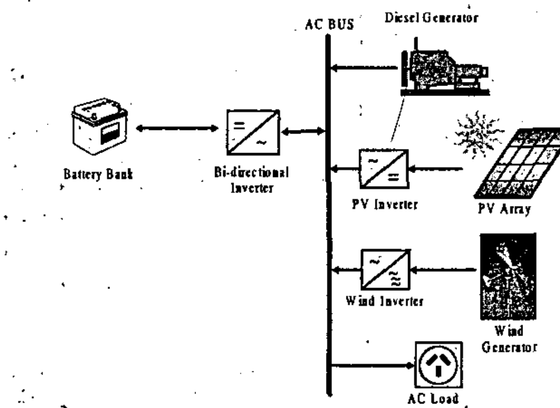


Figure 2: AC Coupled Hybrid System

cases. It is also usually a 'centralised' hybrid system as the power delivered by all the energy sources in conditioned and controlled by a central unit and fed to the user loads via a single point of the distribution grid. The main advantage of central hybrid systems is that they are more robust as they can be controlled more easily than the distributed systems. The communication between components is easy with short distances between components. Usually at each moment only one grid forming unit is connected to the user grid while other units can act as current sources. However DC integration in many cases involves high costs for engineering, hardware, repair and maintenance. More importantly power system expandability for covering needs of growing energy and power demand is also difficult. There is an increasing realization that low cost expandability of the power plant capacity is a prerequisite to make a multi user mini grid sustainable. Thus the system needs to be not only very reliable, economical and robust but modularly structured and therefore easily expandable subsequently.

A better approach in many cases therefore would be to integrate the renewable energy sources on the AC side as in Fig.2 rather than on the DC side. High modularity of the AC coupling technology allows building a single phase or a three phase system. Several battery inverters can operate in parallel on one phase in order to increase the peak power of the power plant. Since April 2001, 3 demonstration system have been operating successfully on the Greek island of Kythnos [8]. This includes a Single phase PV-battery system, a three phase PV-battery system and three phase PV-battery- diesel system. For the first two system types the consequent parallel AC coupling of all components leads to inverter based PV stand alone system with the battery inverter as the grid master. The third system can operate in two operation modes i.e the battery inverter is the grid forming unit and the diesel genset is the grid forming unit. It is expected with standardization of the system design, global market oriented modularization with a small set of expandable inverters, the modular technology can enable integral solutions thus paving the way for establishing industrial series production.[9]

Intelligent management and control algorithms to connect different generators without intercommunication to supply to different users are currently being investigated by our research group at CRESTA. This also includes demand side management when the load is dominated by irrigation systems and supply side management when the public grid, is available from time to time.

3. OPPORTUNITIES UNDER GREEN HOUSE GAS (GHG) MITIGATION INITIATIVES

There are emerging opportunities for expanding the market for hybrid energy systems particularly in the Asia Pacific countries where the potential for deployment of such systems is considered to be large. Kyoto Flexibility

Mechanisms have been developed as market based approaches to containing climate change. One of it is the Clean Development Mechanism. The Clean Development Mechanism (CDM) aims at maximizing the cost effectiveness of climate change mitigation of industrialized countries by allowing them to take up opportunities to cut greenhouse gas emissions by investing in sustainable development projects in developing countries. In return for investing in a sustainable development project that reduces or avoids emissions in a developing country, companies will earn 'certified emission reductions (CERs)' that developed countries may use to meet their Kyoto commitments.[10]

Despite the lack of ratification of the Kyoto Protocol and the lack of a formal global emissions trading system, the Clean Development Mechanism (CDM) provides greater security compared to other emission-reducing projects[11].Preliminary legal frameworks for CDM under the Kyoto Protocol exist. The ability to bank CDM emissions reductions from 1 January 2000(unlike all other emissions reductions sourced from other projects) has been there and institutional support from many Protocol countries such as the Netherlands and also from institutional players such as the World Bank under its Prototype Carbon Fund and the United States under its Activities Implemented Jointly (AIJ) program exist. A few projects have been already contracted. In March 2003 Government of Netherlands approved 18 climate projects in Asian and Latin American region, aiming to cut CO_2 emissions by over 16 megatons. The Netherlands buy these reductions and use them to meet part of its own reduction commitments. [12]. There are also initiatives from private sector. A growing number of companies are adopting 'carbon branding'. The idea involves calculating the GHG emissions associated with the manufacture and use of a product. Emission reductions ("carbon credits") equal to that amount are purchased. The product can then be marketed as not contributing to global warming (carbon neutral), and sold against non-climate friendly products. BP and Avis Europe are examples of a diverse range of companies who have embarked on the scheme. In 2002 BP intended to include CDM projects under its internal trading scheme. The European Union member states have agreed to establish a mandatory emission trading system by 2008; Pilot testing of the scheme is to commence by 2005. Although US has not ratified the Kyoto Protocol, US Global Climate Change Policy released in October 2002 aims at a reduction of CO2 intensity, emissions per unit economic activity, by over 18% over the next 10 years i.e until 2012, by working together with other nations. Apart from US$ 180 million Prototype Carbon Fund (PCF) and programs of the Dutch Government other significant initiatives for project based mechanisms include Singapore-ASEAN Carbon Fund and the programs of Finnish Government.

Evaluation of the characteristics of the early CDM/JI Projects reveals some 100 MtCO2 equivalent (90 from CDM and 10 from JI)[2] GHG reduction has been achieved until February 2003. This is considered only the tip of iceberg as the total GHG abatement potential for CDM and JI projects has been estimated to amount to some 4400 MtCO2.[14]

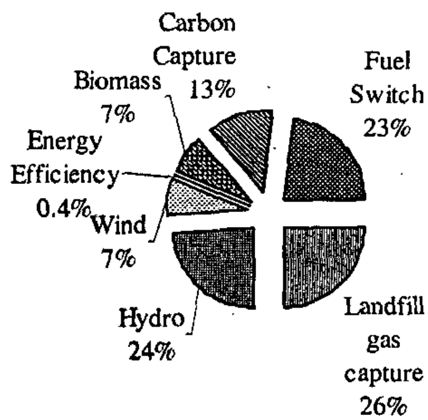


Figure 3. Portfolio of CDM Projects till February 2003

Table 1. Portfolio of Landfill gas recovery projects

Country	Description	GHG reduction [tCO2-eq]
Brazil	Land fill gas recovery	700000
Brazil	Combustion and flaring credits	11800000
Brazil	8 MW power	5208000
S.Africa	20 MW power	4720000

As can been seen from the chart the general preference for projects is somewhat biased towards land fill gas capture while no off grid rural electrification projects have reached the final cycle of the project approval. Although landfill gas capture offers some immediate high carbon abatement opportunity at lower costs it is only seen as a short term solution. Methane[3] contained in the landfill gas is a potent greenhouse gas with Global Warming Potential (GWP) of 21, i.e. 21times that of CO2 over 100 year lifetime and only partial recovery (up to 70%) of it is practically feasible from a landfill. Considerable gas migration happens due to convection and diffusion in a landfill. Gas production rates are moisture dependent. While 60% to 80% moisture results

2 three types of flexibility mechanisms are allowed under the Protocol

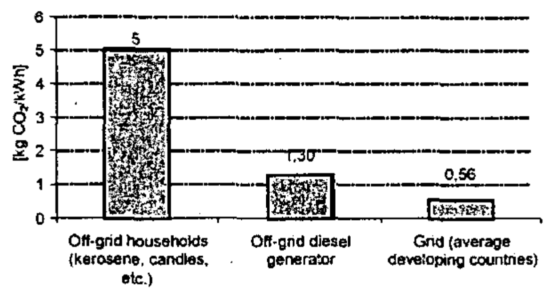
- Joint Implementation (JI): means for an Annex I (industrialized) country to implement GHG reduction projects in another annexe I country to gain Emission Reduction Units (ERU)
- Clean Development Mechanism: means for Annex I country to invest in sustainable development project in a developing country to gain Emission Credit
- Emission trading: free trading of emissions among Annex I countries

3 Methane contributed to some 17% of global Anthropogenic GHG emissions, 11% of which was contributed by landfills (this as high as 37% for US) in 1996

in high gas production, this is never reached in a modern landfill as infiltration of water into the waste is restricted to practical minimum [15].Further secure landfilling practice entails care, management and monitoring of landfills over scores or even hundreds of years. Alternatives to landfilling include waste to energy (WTE) facilities which burn the waste at very high temperatures to reduce its volume by upto 90%. In US approximately 16% of the waste is incinerated in WTE facilities and energy sales alone generally accounts for 35 to 50% of the revenues in the WTE units.[16]. However incineration/combustion of the waste will not solve the problem but can only reduce the quantity of waste to disposed. Lead and Cadmium in the residues pose a disposal problem. This also leads to Mercury and Dioxin[4] emissions into air [17]. On the contrary when used in a fully engineered system Anaerobic Digestion (AD) not only provides pollution prevention but also allows for energy, compost and nutrient recovery. Composting is an energy consuming process requiring around 50-75 kWhr of electricity per ton of waste input while AD is a net energy producing process with around 75-150 kWhr electricity created per ton of waste input [6]. Although a few in vessel AD technologies are available for degrading solid organic wastes, these are comparatively expensive with commercial treatment processes costing approximately $US 100 per ton of 'as received' organic waste. In contrast a modern 250 ton/day landfill costs approximately $US 30/ton which explains the limited market share of AD. [18]

The costs of conventional anaerobic digestion plants for municipal waste can be significantly reduced by using a modularized design which requires minimal handling of the solids during the treatment process. One such hybrid system design is being currently developed by our group under a joint project of Murdoch University and Curtin University of Technology, Perth, West Australia. This design also incorporates *in situ* drying of the stabilized residue by having a heat recovery system to extract waste heat from the exhaust and coolant of the diesel generators which operate with significant fuel replacement from biogas. The dried residue can be marketed as compost. As an example we illustrate the potential for power generation and greenhouse gas mitigation from municipal solid waste in Bangalore. About 3700 tonnes of municipal solid waste is generated in Bangalore every day [19]. Most of the waste is simply dumped. It can be estimated that 216,450 m^3 of methane would be generated every day from these dumpsites. If the organic fraction of the municipal solid waste were anaerobically digested potentially 600 MWh of energy per day can be generated. Setting up a facility such as this would require significant investment in infrastructure starting from implementing source collection, transportation, transfer stations with materials recovery facilities and perhaps a centralized anaerobic digester. However, currently systems appear to be in place to divert, collect and process market wastes. About 400 tonnes per day of market waste is composted [20]. If this waste were to be anaerobically digested, potentially 70 MWh of electricity can be generated per day. The residue produced from the process can be dried and sold as compost. The quality of this compost would be the same as that is produced now, if not even better. Depending on the economies of scale, several modular hybrid power plants can be established combining other renewable energy sources wherever feasible.

Although waste to energy systems of above description would appear to ideally suit a CDM project there are barriers to overcome before this can actually happen. In [21] the Current design of the modalities and Guidelines and the competitive nature of the CDM, high transaction costs and low per installation carbon abatement have been recognized as the factors which currently lead to marginal benefit to off grid or small (<1 MWe) projects from CDM. In [22] it is estimated a small project would need to generate a minimum of 20000 CERs (at 5$/t$CO_2$) or 5000 CERs (at 20$/tCO_2) to cover the initial transaction cost of CDM process. This is usually not within the reach of a small hybrid system project. However these projects rank high in terms of fostering sustainable development of the host country (one of the major goals of CDM) and in offering long term solution to climate change which should be in favor of devising a way to include the small projects. The rate of displacement of CO_2 from off grid projects is high as reflected in the figure below.



(Source: Ybema et al, 2000; Lazarus et al, 2000; Bosi, 2001)

Figure 4. CO2 Reduction potential using different references

Developing the baseline (what would have happened in the absence of the project) is a crucial first step in a CDM project because it is used as a reference point for comparison of all alternative scenarios. A UNEP/OECD/IEA[5] Workshop on Baseline Methodologies recommended a standardized baseline and a fast tracking option for off grid renewable energy projects. In [21] a methodological approach is proposed for streamlining procedures specifically aiming at projects for solar homes systems. Certification, verification and sale of CO2 savings from a number of small projects can be bundled and sold

[4] 2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD) is the most potent chemical carcinogen ever evaluated by US EPA (Environmental Protection Agency).

[5] United Nations Environment Program/Organisation for Economic Cooperation and Development/International Energy Agency

without the buyer having to be directly involved in the individual projects on the ground. This large pool of projects could balance any fluctuation in CO2 savings as well as make CO2 monitoring worthwhile. This creates the need for a network of stakeholders of small projects. Considerable experience exists in the Asia Pacific region more so in India with regard to cooperatives particularly in the agricultural sector. CDM executive board is mandated by UNFCCC to continuously monitor, streamline and simplify the CDM procedures. Panels on methodology, accreditation and small scale CDM assist the Board in accomplishing the refined procedures based on the experience gained and input from various stakeholders. The authors hope concerted efforts of stakeholders of small projects will eventually result in significant number of small and off grid CDM projects resulting in market development of Hybrid Energy Systems.

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