MIGRATING TO A SUSTAINABLE ENERGY SYSTEM: DISTRIBUTED GENERATION AND STORAGE, FUEL CELLS AND HYPERCARS

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Abstract

This paper examines a number of issues in sustainable energy generation and distribution, and explores avenues that are available for integration of our society's energy supplies. In particular, the paper presents a way in which transport vehicle energy supplies could be integrated with distributed generation schemes to achieve synergistic and beneficial outcomes. The worldwide energy system contains fundamental problems that result directly from the use of unsustainable fuels and a lack of energy system integration. There is a need to adopt an integrated, sustainable energy system for our society.

The adoption of distributed generation could result in beneficial restructuring of the energy trade, and a change in the role of energy providers. Inherent benefits in distributed generation schemes would directly combat barriers to installation of renewable generation facilities, which might prove distributed renewable energy sources to be more feasible. The presence of fuel cells, batteries, power electronic inverters and intelligent controls in vehicles of the future provides many opportunities for the integration of vehicle energy supplies into a distributed generation scheme. In such a system, vehicles could play a major role in power generation and storage.

1. INTRODUCTION

Humans are great consumers of energy. Unfortunately, the energy supply for human society has never been treated as a system – the supplies of the same commodity (energy) to the different consumption sectors are treated as separate and different problems.

Such an approach has succeeded to this point because of the historical abundance of various fossil fuels on our planet. However, fossil fuel reserves are finite, and will someday be expended. Furthermore, the various fossil fuels may be fully depleted at different times. With our current worldwide energy system, a transition to renewable (sustainable) energy might produce problems in energy availability for certain consumption sectors.

It is likely that the long-term sustainable energy solution will be a hybrid system incorporating renewable and nuclear sources, and a fuel infrastructure centred on sustainable fuels such as hydrogen and methanol. Furthermore, because of the unreliability associated with renewable energy sources, it is likely that no single source will dominate, and large storage energy facilities will be required. Future energy supplies will require treatment as a fully integrated system; otherwise functionality may be lost, and operational costs significantly increased.

This paper examines a number of the foreseen issues in energy generation and distribution in further detail, and explores some of the avenues that are available for integration of our society's energy supplies. In particular, the paper presents a way in which transport vehicle energy supplies could become integrated with distributed generation schemes to achieve synergistic and beneficial outcomes.

2. PRESENT PROBLEMS

2.1 Our Dependence on Finite Fossil Fuel Reserves

The majority of primary energy consumed by our society comes from fossil fuels. Crane [1] suggests that worldwide annual primary energy consumption is 2.5 cubic miles of oil (CMO), equivalent, of which 2.1CMO comes from fossil fuels (coal, oil & gas). Hydroelectric power contributes 0.2 CMO, while nuclear produces the remaining 0.2 CMO. Other renewables such as solar, biomass or geothermal account for less than 0.03 CMO combined.

The exact amount of remaining fossil fuel reserves is in dispute, but there is no doubt that fossil fuel reserves are indeed finite. Although new reserves may be found, and extraction technologies might improve, there will come a point where the energy required for extraction will be greater than the energy gained. At this point, a transition to renewables will become more economical, in addition to being necessary from a viewpoint of sustainability.

Of particular concern is the future energy supply for transportation. Almost all transportation runs on liquid fossil fuels (derived from oil). At our present levels of consumption (1CMO per year), oil levels may be fully depleted in less than 50 years [1].

2.2 Non-systematic approach to energy supply

Energy supplies to the various consumer sectors of human society have never been treated in a systematic way. Sources of energy have always been chosen based upon minimum cost and maximum convenience, with little focus being placed on integrated energy supply networks, multi-fuel capability, or on alternative sources of energy for times of contingency. (An excellent example of this last point was the recent Victorian gas crisis.)

What appears to have resulted is that each consumer sector has its own unique energy source that is not shared with other groups to any great extent. For example, in Queensland, 97% of power generation is from coal, most transportation energy comes from oil, and industry is by far the majority consumer of natural gas [2].

2.3 Problems in Personal Transport

Personal transport is a major consumer of worldwide oil reserves. Furthermore, current vehicle designs are highly inefficient in performing their prime function of transporting people and cargo. The current trend in western automotive manufactures of producing inefficient 4WD urban assault vehicles for personal transport does not help this situation. The personal automobile plays an integral role in Western society and it is likely that such vehicles will still be common when fossil fuel reserves become scarce. As such there is a need to move towards a new motive power source and vehicle platform that can provide sustainable personal transport into the second half of the 21st century.

Although vehicles consume a large portion of the world's energy, they are not well integrated into the current energy system. The installed generating capacity of mechanical power in vehicles is of a similar magnitude to base electrical generating capacity [3], yet vehicles are not considered to be a possible source for power generation. It is interesting to note that the total residential electrical power consumption of Australia in 1997 could have been provided by 20kW sourced from each of the new cars sold in Australia in that same year.

3. CONTEMPORY SOLUTIONS:

3.1 Increase the efficiency of Generation

An effective means of extending fossil fuel reserve lifetimes and reducing pollutant emissions levels is to increase the efficiency of power generation. This method has received encouraging levels of interest from the power generation industry, and from legislative bodies and industry in general.

The Queensland government has just released a new energy policy which encourages the replacement of coal-fired power stations with more efficient gas-turbine combined cycle plants, and the adoption of natural gas plant with cogeneration as a convenient means of power and heat generation for industry [2].

Energy generators such as CS Energy [4] are investing funds into projects such as their coal-gasification program and Swanbank landfill utilisation project to produce high quality, low carbon intensity fuels for these high efficiency plants.

3.2 Reduced energy consumption through improved end-use efficiency.

By far the most fuel and cost effective means of reducing energy usage is to increase end use efficiency. Such an approach has synergistic benefits because it not only reduces the energy needed for end users, but also reduces the quantity of energy lost in the processing, generation and distribution stages.

A prime example of poor end use efficiency is the use of electricity for heating applications. Heating is obviously more efficiently obtained by directly burning fuels for the heating application, or by utilising waste heat from power production (such as cogeneration in industry).

In the residential sector, this means that the adoption of an energy-efficient "all electric" household may cause more harm than good. Residential users should utilise a combined energy supply of gas for heating applications, and electricity for 'power' applications.

Reduced energy consumption can extend the useful lifetime of fossil fuel reserves, and also reduces the size of renewable generation facilities needed for energy sustainability, and reduces the rate at which these would need to be installed, making renewable energy sources appear more viable.

3.3 Use of Renewables

It is generally agreed that renewable energy sources will ultimately satisfy the long-term sustainable energy needs of society. Because of this, renewable generation sources such as solar (photovoltaic and thermal), wind, and biomass have attracted large amounts of interest in recent years. In Australia, the government mandate that 2% of power will be obtained from renewable generation by 2003 is forcing consumers to examine renewable sources. Other government incentives such as the $5.50/W subsidy for solar installations are also encouraging consumers to consider renewable generation options.

However, the scale of installed renewable generating capacity is small, and several barriers exist to prevent a full scale, widespread introduction of renewable generation sources. These include:

- Size/scale of renewable generation plant
- Cost (or cost per kW)
- Unreliability of supply and the need for energy storage

A typical characteristic of renewable energy sources is their low surface power density (in terms of W/m^2). To make any significant contribution to our planet's power generation requirements, vast areas of land will need to be allocated to renewable generation facilities. In the case of photovoltaic solar generation, for example, an area of between 25,000-40,000 square miles would be necessary to produce 1 CMO/year. For biomass generation, 700,00-2,000,000 square miles would be needed to produce 1 CMO/year – an area almost the size of the United States [1].

The problem becomes more alarming when consideration is given to the rate at which renewable generation facilities must be installed to meet our society's future energy demands. To produce 1 CMO/year in 50 years time, photovoltaic solar panels would need to be installed at a rate of 12 million 200W panels per week for the next 50 years. This is equivalent to installing 1,500 1200kW wind turbines per week, or one 1000MW nuclear reactor per week over the 50-year period [1]. Further delays in the widespread installation of renewables can only worsen these figures.

The cost of renewables is another factor preventing widespread installation. In terms of plant-only capital costs, the production of 1 CMO/year from photovoltaic solar would be ten times as expensive as from oil itself, and production of 1 CMO/year of methanol from biomass would be seven times as expensive [1].

The final problem with renewable generation sources is the unreliability/fluctuation in generation output. To effectively combat this problem, large storage capacity will be a mandatory requirement of the future energy system.

In summary, the successful widespread installation of renewable energy sources will require a synergistic introduction that utilises pre-occupied areas of land, encourages a high rate of installation, offsets the initial capital costs and provides adequate levels of energy storage facilities for the renewable generation system.

3.4 Electric Vehicles (EV) and Hybrid Electric Vehicles (HEV)

Electric vehicles were the most prominent form of motor vehicle before 1900, but due to very low specific energy density of batteries these vehicles were overtaken by the introduction of internal combustion engine vehicles with electric starter motors. Most electric vehicles currently produced are conversions of internal combustion vehicles. This approach is inappropriate and results in greater-than-necessary energy use in the vehicle and a poor public perception of electric vehicles in general.

Hybrid vehicles became popular during and after the 1970's oil crisis and have recently come to light again with the Partnership for New Generation Vehicles and the release of the Toyota Prius and the Honda Insight. For the future most car manufactures are moving to an integrated starter and alternator unit placed in the position of the engine flywheel, and increase to a 42V system voltage. This system is considered to be a "mild" hybrid that gives the opportunity of halving fuel consumption for inner city driving.

Both EVs and HEVs can reduce the required levels of primary energy generation and improve end-use efficiency, but these vehicles are far from optimum and may find a limited future in a sustainable energy system.

4. NEW APPROACHES AND TECHNOLOGY WHICH CAN CHANGE THE DIRECTION

4.1 Systems Approach to Energy

The fundamental changes in our attitude towards energy call for a systems approach to our worldwide energy system. A systems approach recognises that, by necessity, energy must be provided in many different forms; electricity, heat, mechanical power and chemical fuels, but that the overall energy supply should be encompassed by a single, fully-integrated system. It examines issues in generation, storage, distribution and end-use as a combined problem, not as separate problems to be dealt with in isolation. Such an approach could drastically reduce our society's primary energy needs, and would greatly improve the end-utilisation of supplied energy.

4.2 Distributed generation

From a fundamental perspective, distributed generation is attractive because it is better to generate energy at its point of use, rather than at a remote location.

Fast maturing distributed generation technologies such as fuel cells, gas turbines and solar systems all offer the opportunity to generate both electricity and heat efficiently at the point of use, making them ideally suited to distributed generation networks. The benefits resulting from distributed generation schemes can directly oppose the barriers to installation of renewable generation facilities, making renewable energy sources appear more economically and practically feasible.

Distributed generation systems are already proving feasible for large energy intensive industries and utilities, and should do so for hospitals, hotels, offices and apartment complexes. Ultimately, such systems could be placed in individual homes.

4.2.1 Advantages to the Consumer

By generating at the point of use, the consumer specifically and society generally both realise a number of advantages.

The efficiency of the conversion of primary fuel to electricity can approach that achievable by large centralised generation facilities. This is compounded by the removal of transmission losses, since the generation is at or near the point of use.

However, the opportunity to utilise heat released in the energy conversion process is the real motivation to place these micro generators at the point of use. In centralised generation, "waste heat" is a liability, requiring large cooling towers to reject the heat to the environment. In distributed generation, this heat can be used for hot water and space heating, which is usually the largest part of the domestic energy bill. Seen in this light, the conversion of energy into "useful work" approaches 100% (excluding parasitic losses).

Mass-produced and marketed like other consumer white goods, such micro-generators could rapidly migrate into typical households, replacing both hot water and heating systems, and producing quality electrical power for household use. The additional cost would soon be recuperated through the now completely displaced heating or electricity bill, depending upon your perspective.

4.2.2 Advantages to the Utility

The traditional provider of electricity also realises a number of advantages in distributed generation.

Transmission losses are reduced, perhaps significantly if the mean power generation capacity matches the mean power consumption at that location. The need for the upgrading of existing transmission capacity may be postponed or eliminated.

When comparing a distributed system to a centralised generation facility, the capital investment and risk required to increase the reserve generation capacity is greatly reduced or even eliminated, for several reasons.

In a distributed system, capacity is added to the network incrementally, that is, in small amounts for small capital outlays, but with great frequency. The increase in network generation capacity increases smoothly. In contrast, centralised generation is added to the network infrequently in large amounts.

The centralised facility requires a much greater lead-time for planning, approval, construction and commissioning. Once brought on-line, there is a large excess of generating capacity that may take many years to diminish, which depresses the price of the electricity sold. The return on the capital investment is initially zero, and is then low.

A distributed installation has a lower design cost, and can be mass-produced to reduce costs. Production, installation and commissioning time can be measured in weeks, similar to consumer white goods. If driven purely by the demand for electricity, installation is scheduled on a much shorter lead-time, only as required, and soon after can be delivering its full generating capacity to the network.

A more likely scenario is that the investment in distributed generation plant will be made by the consumer of the electricity, rather than by the utility. The utility then has no capital outlay or risk at all. If marketed correctly, the benefits to the consumer will be significant enough to motivate the purchase.

Other secondary costs such as maintenance costs of generation facilities, and the installation of additional power transmission infrastructure will be reduced or eliminated.

4.2.3 Changing role of Energy Providers to Energy Brokers

The adoption of distributed generation would bring about changes in the role of companies traditionally responsible for generation, transmission, distribution, supply and retail of energy. Energy providers (such as electricity and gas retailers), and other new players would become energy "brokers", buying and selling energy, and providing the means to transfer energy between transacting parties.

In Queensland, the electricity retailer Energex [5] has already taken a step towards selling energy, rather than just electricity, through the acquisition of a local gas utility.

The more drastic change in thinking for retailers will be the move from selling energy to transferring or brokering the same. A direct consequence of this adjustment will be that consumers wishing to generate and sell power, rather than being seen as a nuisance, will be offered realistic prices for their energy. Drawing an analogy to the world of finance, energy brokers will come to value their distributed consumers/generators as much as financial institutions value their loans/investors.

4.3 Fuel Cells

Unlike heat engines, fuel cells are not limited by theoretical thermodynamic efficiency limits and are therefore capable of producing electrical power at an efficiency of well over 50%. Fuel cells have the added bonus of having no moving parts and hence have proven to be reliable and require low maintenance. Worldwide many billions of dollars are being invested into researching fuel cell technology for use in stationary power generation, vehicles and portable low power applications such as mobile phones and laptops. At the moment there are a number of different technologies being considered, with PEM (proton exchange membrane) being chosen by most developers.

The first probable widespread application for fuel cells will be in stationary power generation, because of the higher acceptable capital cost in this application (for stationary power generation, costs of US$1500/kW would be acceptable, while vehicle fuel cells would be required to cost below US$60/kW) [3]. Stationary applications such as large office complexes or utilities would be a useful first application for fuel cells. These applications often require the installation of UPS and have large heating or cooling requirements, which could be achieved by waste heat utilisation, further reducing the overall cost of the fuel cell.

There is also an opportunity to utilise fuel cells in residential homes. General Electric [6] is due to release a 7kW home fuel cell unit in 2001. This unit produces electricity at an efficiency of 40%, but has an efficiency of greater than 75% when used for cogeneration to provide heat for hot water or home heating.

4.4 HyperCars

The Rocky Mountain Institute [7] formally introduced the Hypercar concept, although its origins seem to stem from solar vehicle racing. The concept proposes a large reduction in both vehicle mass and aerodynamic drag. The resulting lower power required to drive the vehicle will result in a smaller, lighter drive train, which then further reduces the mass of the vehicle. This concept of mass decompounding and ultra low drag combined with low power accessories and a highly efficient hybrid electric drive train is shown to result in a family vehicle with a fuel consumption of between 1-2 L/100km.

Most predictions suggest that Hypercars will be powered using fuel cells. The fuel for these vehicles is still uncertain, but it is likely that the first fuel cells will utilise methane, natural gas or petrol with a reformer to internally create hydrogen. As fuel cells become more prevalent, it is likely that hydrogen will be supplied as a fuel for vehicles, which will eliminate the need for an on-board reformer.

Although Hypercars offer the prospect of drastically reduced primary energy consumption in the transport sector, with a successful transition to alternative fuels, it is the inherent potential for Hypercars to participate in an integrated, distributed generation system that is of major interest in this discussion.

5. IMPORTANCE OF HYPERCARS TO AN INTEGRATED ENERGY SYSTEM WITH DISTRIBUTED GENERATION

Hypercars contain several key components that could play an active role in a distributed generation system.

The first is the on-board energy storage medium(s), such as a battery or ultra-capacitor pack, or a fuel tank in combination with a regenerative fuel cell. These components are responsible for storing the energy required for the vehicle’s driving range and supplying the short-term peak loads required in a vehicle. The ability to supply (or absorb) large amounts of power (tens of kW) and energy (tens of kWh) for extended periods is inherent in Hypercars.

In their hybrid-electric drive trains, Hypercars control the delivery of stored energy to their electric motors through large power electronic converters. For, the majority of Hypercar motors (synchronous and induction drives), the outputs from these power converters are a clean 3-phase AC supply.

The final Hypercar component of significance to distributed generation is the on-board control and intelligence system. Hypercars will contain the state-of-the-art in control, intelligence and communications technologies and will be configured for connection to a variety of communication networks, such as the internet and mobile phone communications, or an integrated vehicle service network.

Given the expected size of the Hypercar fleet and the fact that vehicles are idle 96% of the time, these three components could offer many benefits to a distributed energy system in terms of generation, storage, connection and control. The on-board storage medium is capable of generating and absorbing power from the grid at high efficiency while providing substantial amounts of storage; the on-board power inverter simplifies the connection of the Hypercar to the power grid; the on-board electronics provides enormous possibilities for integrated control of the distributed Hypercar network.

"The economics of the world itself changes when you park a car and then use its fuel cell to generate electricity for your home. The power grid of an entire country begins to look like the Internet rather than a mainframe (computer)."
Mr P.I. Bijur, Chairman and CEO of Texaco [3]

Further benefit could be achieved by utilising the waste heat produced by the fuel cell when the Hypercar is parked in a residence or at a place of work. Also, if the Hypercar was powered with a hydrogen fuel cell then it could produce a steady supply of water pure enough for normal household use.

Such claims can seem a little outrageous at first glance, but they will appear far more achievable if some thought is given to designing Hypercars into the integrated, distributed energy generation, storage and supply network for residences and utilities.

6. CONCLUSION

The worldwide energy system, which includes generation, storage, distribution, supply and end-use, contains fundamental problems that result directly from the use of unsustainable fuels and/or a lack of energy system integration. There is a definite need to adopt an integrated, sustainable energy system for our society, otherwise energy system functionality may be lost, and operational costs significantly increased in the future.

Despite present methods of addressing problems in our energy supplies, there are new techniques and technologies that offer the prospect of revolutionising our society's energy system.

The adoption of distributed generation could result in beneficial restructuring of the energy trade, and a change in the role of energy providers to that of energy brokers. Furthermore, inherent benefits in distributed generation schemes would directly combat the barriers to installation of renewable generation facilities, which might make the scenario of distributed renewable energy sources more feasible.

It is likely that Hypercars are the sustainable future of personal transport vehicles. The presence of fuel cells, batteries, power electronic inverters and intelligent controls in these vehicles provides many opportunities for the integration of vehicle energy supplies into a distributed generation scheme. In such a system, Hypercars would play a major role in power generation and storage.

However, the energy system elements examined in this paper are extremely complex, with a multitude of conflicting issues that impact upon many areas of our society. It would be unreasonable to expect a six-page discussion to be able to properly examine all of the factors that might contribute to a future sustainable integrated energy system for our society. The responsibility falls upon all consumers, professionals, academics, industrial groups and legislative bodies to work collaboratively upon this global issue, and formulate the system that will guarantee our society's energy supplies in the future.

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