Energy Services: Back to Basics and Up to Hybrids

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ABSTRACT

The provision of energy services has always held a vital, central role in the support of Antarctic research operations. Progressive increases in research activities and in the standard of facilities have combined to expand the scale and importance of the infrastructures dedicated to the provision of energy services. These infrastructures rely almost exclusively on imported fossil fuels.

Over the last decade there has been an increasing emphasis on the reduction of both the quantity of fossil fuels used and the environmental and operational impacts of the infrastructures. As a result, several wide-ranging studies have been conducted, focusing on the characteristics of the current systems and requirements, on the resource potential for renewable energy production, on the technological and operational aspects of renewable production and energy storage and on the potential of advanced energy management systems.

This paper reviews the basic concepts of energy requirements and energy production and distribution. It then outlines how the evolution of the stations' energy networks towards less fossil fuel dependence and decreased impacts is linked to the evolution towards hybrid networks mixing multiple power generation options and interactive electrical-thermal combinations controlled by advanced energy management systems.

The focus is on fixed, hybrid station energy supply networks providing heat and electricity without large, expensive add-on storage capability and hence retaining a minimum amount of fossil-fuel based power production. The aim is to provide a clear, synthetic view of the main guiding principles of the design and operation of the most realistic, reliable options available with current and emerging technologies.

This paper also clarifies the reasons behind the current development of energy management strategies and new equipment installations at the Australian and French Antarctic research stations. It can be read as an introduction or complement to papers and posters presented at the SCALOP 2000 symposium by Bonnice et al, Alain et al, Magill et al and Williams et al.

BASIC NETWORK STRUCTURE

The stations' energy supply networks are established to provide energy services required for the good operation of the stations in support of research activities. The structure of the network is based on the fundamental flow: Energy Production to Energy Carrier to Energy Service.

Figures 1 to 4 outline different configurations of this fundamental structure. Generator sets, boilers and renewable systems produce a mix of heat and electricity. Electricity is used to satisfy the basic electrical demand of non-heating services plus a certain amount of the heating demand. Heat is used to satisfy the rest of the heating demand. The quantity and scheduling of the electricity diverted to heating services is the element that can provide the stability and optimal efficiency of the entire network.

Various primary energy production devices feed a combination of two energy carriers, heat (thermal carrier) and electricity (electrical carrier) which in turn power the energy services divided in two main categories, heating services and non-heating services (see Figures 1 to 4).

ENERGY SERVICES

Energy Services are essentially divided in heating and non-heating services.

Heating services are the services whose primary function is to deliver heat. Examples are space heating, domestic water heating for showers, oven heating, water heating in dishwashers or washing machines. These heating services have two important characteristics:

- an inherent inertia hence an **inherent buffer storage capacity**.
- the capability of being **powered with a combination of heat and electricity**, combination often very flexible.

The operation of heating services usually requires the simultaneous operation of less intensive, accessory non-heating services such as the operation of a pump or a control system.

Non-heating services are all the other services. Examples are the operation of a pump, a computer, communications or lighting. It must be noted that the operation of these services may dissipate heat as a by-product but it is not their prime function and more importantly it is not the amount of heat that will determine the level of operation of the service. These non-heating services have:

- no inherent inertia hence **no inherent buffer storage capacity**.
- to be **powered exclusively by electricity**.

Most of these services tend to operate 'when needed' with little scheduling or variation flexibility. These services control the minimum, 'bare' electrical load demand.

ENERGY CARRIERS

Stations' energy networks usually include both an electrical and a thermal energy carrier. The presence of the thermal carrier is not strictly necessary since all heating services could be powered exclusively by electricity but it is generally well justified by the facts that 1) a large amount of waste heat can be recovered on the electricity generation process and 2) heat-only can be produced much more efficiently than electricity-only.

The electrical carrier takes the form of an electrical cable network or electrical grid reticulating electricity around the station.

The thermal carrier usually takes the form of a pipe network reticulating heating hot water (HHW) around the station. Heat is then delivered to the services through heat exchangers. Operation of the HHW network requires a minimum of electricity for the circulating pumps and controls.

FOSSIL FUEL BASED ENERGY PRODUCTION

Most stations currently generate the bulk of their electricity and heat with diesel or kerosene fuelled generator sets and boilers.

Generator sets are designed to generate electricity in an alternator driven by an engine but a large proportion of the heat dissipated in the engine can be recovered from both the jacket water and the exhaust. When operating within its optimal load range, usually between 80 and 100% of its rated capacity, a good current model generator set will convert 37% of the fuel energy content into electricity and 42% into recoverable heat, giving a combined cogeneration efficiency of 79%. It must be noted that operating the generator outside of its optimal range will not only decrease these efficiencies but also increase the wear and tear of the engine. It will increase the cost of maintenance per unit of electricity produced. It is important also to note that the quantity of heat produced with the generator sets is only function of the electrical demand, not of the heat demand and that the production of any excess heat not required by the station effectively corresponds to a decrease in production efficiency.

A good boiler will convert 80% of the fuel energy content into heat and will only be switched on to respond to heat demand. A boiler can easily be operated in on-off sequences at its optimal load because of the inherent inertia of the heat carrier behind it.

These conversion or production efficiencies are relative to the 'lower heating value' (LHV) energy content of the fuel. The LHV of the special Antarctic blend diesel fuel (SAB) used by the Australian and French Antarctic programs is 9.8 kWh per litre.

This means that burning one litre of SAB Diesel fuel will produce

- 3.6 kWh of electricity and 4.1 kWh of heat in a generator set
- 7.8 kWh of heat in a boiler.

RENEWABLE PRODUCTION

The fossil fuel based ‘on demand’ production can be supplemented by heat or electricity produced ‘ when available’ by renewable resources conversion system. The most likely conversion systems to be used are wind generators and photovoltaic panels producing electricity and solar thermal systems producing heat.

ENERGY NETWORK PRINCIPLES

The “true efficiency” of the system is directly related to the output-input ratio where the output is the effective service in support of research activities and the input is the quantity input into the system. For fuel efficiency the input is the quantity of fuel and for financial efficiency the input is the financial cost supporting the system, including purchase, installation and maintenance costs. It is not the intention of this paper to discuss what an “effective” service may be or how it may be assessed. It will be assumed here that the services provided are both legitimately needed and fully used.

The main guiding principles are:

- The total electrical load (bare electrical load + load diverted to heating services) must be stable and stay within the optimal operating range of the generator set(s).
- The heat recovered from the generator sets must be inferior to the heat demand (demand of heat on the thermal carrier from the heating services).
- The power produced by renewable systems should be used as much as possible. The resource may be free but the purchase, installation and operation of the conversion system is not free and any wastage corresponds to an increase in the cost of the useful energy produced.

Figures 1 to 4 outline four different configurations of this fundamental structure. Generator sets, boilers and renewable systems produce a mix of heat and electricity. Electricity is used to satisfy the basic electrical demand of non-heating services plus a certain amount of the heating demand. Heat is used to satisfy the rest of the heating demand. The extent and flexibility of the capability to divert electricity to heating services is the element that can, with adequate control, provide the stability and optimal efficiency of the entire network.

The management of the diversion capability requires an advanced, automated management system with control over a large number of energy services. The potential of the management will depend on the number and variety of heating services controlled but also importantly on a significant thermal inertia of the services.

Figure 1 shows the common configuration still widely used. This is essentially a fossil fuel based system with no diversion capability. The thermal carrier feeds a first group of heating services while the electrical carrier feeds a second group of heating services as well as the non-heating services. The two groups of heating services are dissociated and are both calling for power when it is required by their own operating rules without any regard to the operation of the rest of the system. Such a system is characterised by very limited load shedding capabilities, relatively high bare loads and potential heat excess.

A typical, progressive evolution of the configuration shown in Figure 1 involves an increased control of the heating services via a central system capable of some alteration of the heating services' "output" operating rules depending on the state of the entire system. For example when the load on the generators is too high a building usually set for a minimum temperature of 18°C may be allowed to go down to 15°C or the heating may be cut on washing machines.

This can progressively lead to the configuration shown in Figure 2, a fossil fuel based system with extensive diversion capability. In this configuration, about all heating services are primarily fed by the thermal carrier but include electric heating elements that allow the electrical carrier to provide any proportion of their needs. A centralised system controls not only the output operating rules but also the repartition of thermal and electrical power provided to the system. The bare electrical load is restricted to the provision of non-heating services and the heating services can be used for load shedding and scheduling to provide a stable load on the generators as well as for balancing the electrical and thermal productions to reduce potential for excess heat.

Figure 3 shows a hybrid system with no diversion capability. This is the common, basic system with no diversion capability shown in Figure 1 to which renewable production has been added, bringing highly variable and essentially unpredictable (especially for wind) inputs into the electrical and thermal carriers. If the renewable input capacity is high, it does increase the occurrences of unstable operation of the generator, of operation outside of the generators' optimal operating range and of excess heat production. It results in a decrease of the effective efficiency of the fossil fuel system and in the case of very high renewable input capacity can result in significant excess production. It must however be noted that such behaviour if kept within limits can still provide both fuel and financial "true efficiency" improvements over a purely fuel-based system.

Figure 4 shows an advanced hybrid system with extensive diversion capability. This is the system shown in Figure 2 to which renewable production has been added. The extensive diversion capability allows an optimal management of both the fuel-based production and the use of the renewable production. In particular it allows optimisation of the effective utilisation of renewable electricity production without extensive electrical storage capacity. For example when the wind blows a large wind farm capable of producing a little bit more than the overall station load can power the entire station with all heating needs fed through the diversion system with production variations absorbed by the inertia of the heating services. Variations of the production around the level of the bare load can be handled by a limited electrical storage device such as a flywheel which can absorb short term shortfalls and if necessary provide the time necessary to start up a generator. Once generators are started the diversion function is constantly adjusted, as both station load and wind production fluctuate, to provide both a stable operation of the generator within its optimum range and an effective use of the generator's heat recovery.

CONCLUSION

Well designed, advanced centralised energy management systems controlling a large number of heating services

- fed by a flexible combination of heat and electricity and
- including a significant thermal inertia

are the key to

- optimising the efficiency of fossil fuel based production
- allowing a large penetration of renewable energy production with little waste of excess power, a limited need for large electrical storage capacity.

Such energy management systems can be implemented progressively to evolve from common, basic fossil-fuel systems to advanced, effective hybrid systems where fossil-fuel and renewable production can coexist with little conflict and achieve high efficiency. But it is clear that the establishment of well-defined, adequate operating rules is crucial to the creation of a successful management system. This requires a clear understanding of basic energy concepts and a clear view of the operation of hybrid stations' networks.

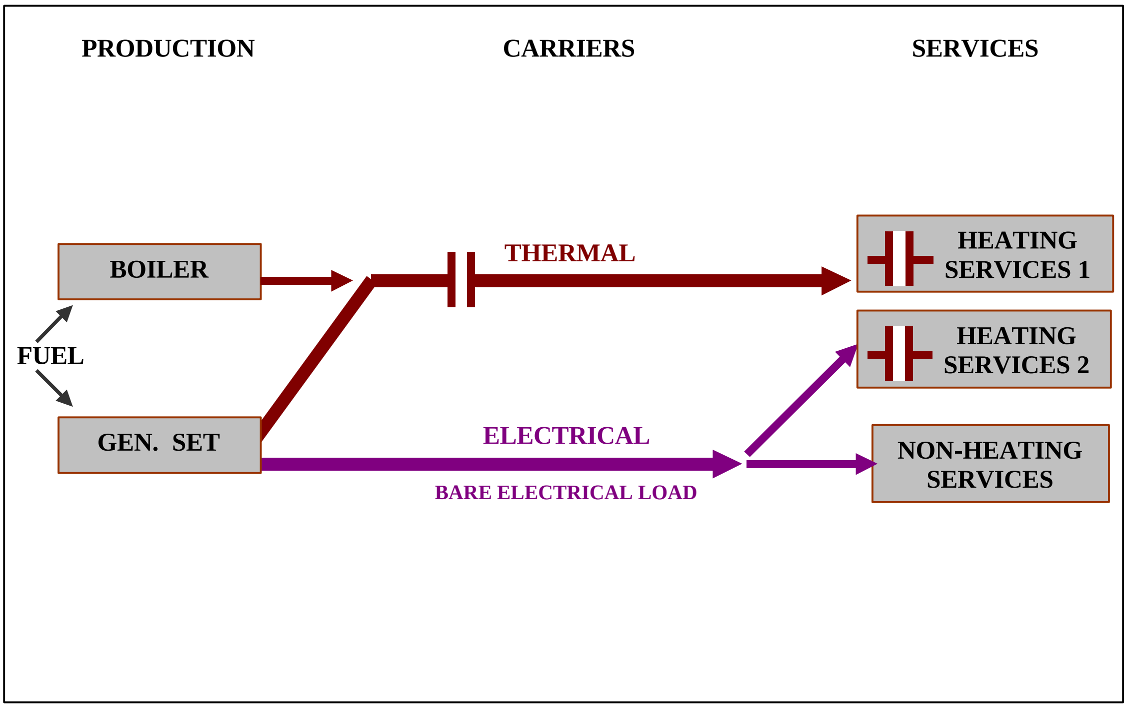

Figure 1: Fossil-fuel based system with no diversion capability

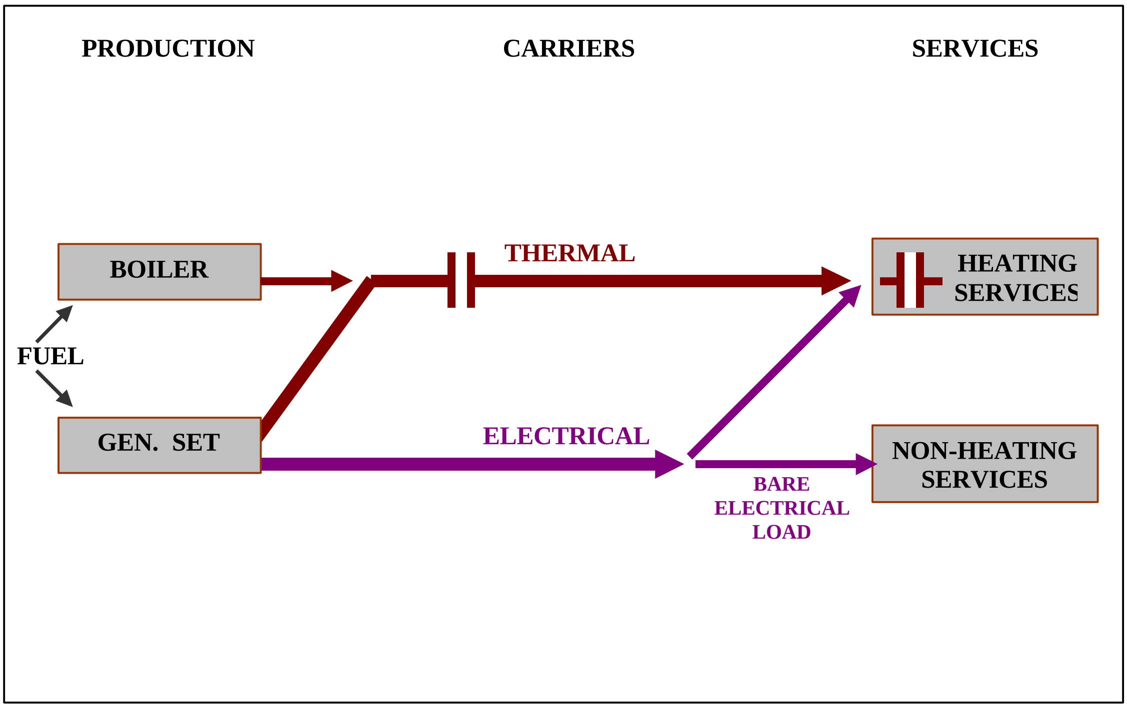

Figure 2: Fossil-fuel based system with diversion capability

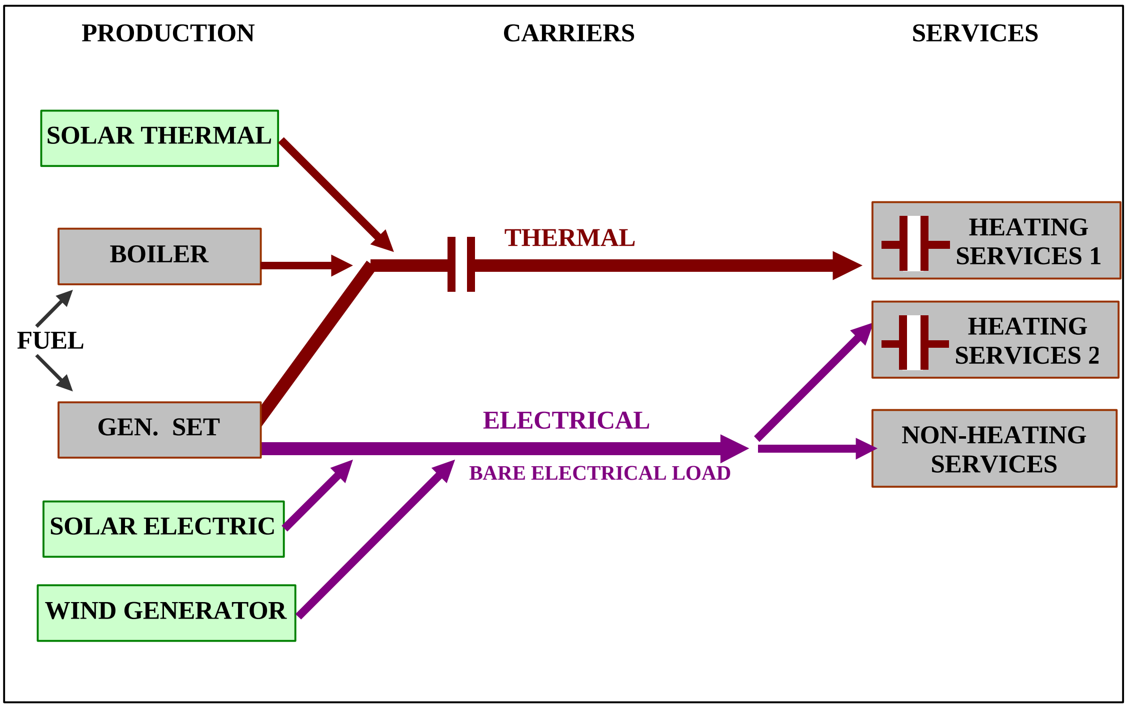

Figure 3: Hybrid system with no diversion capability

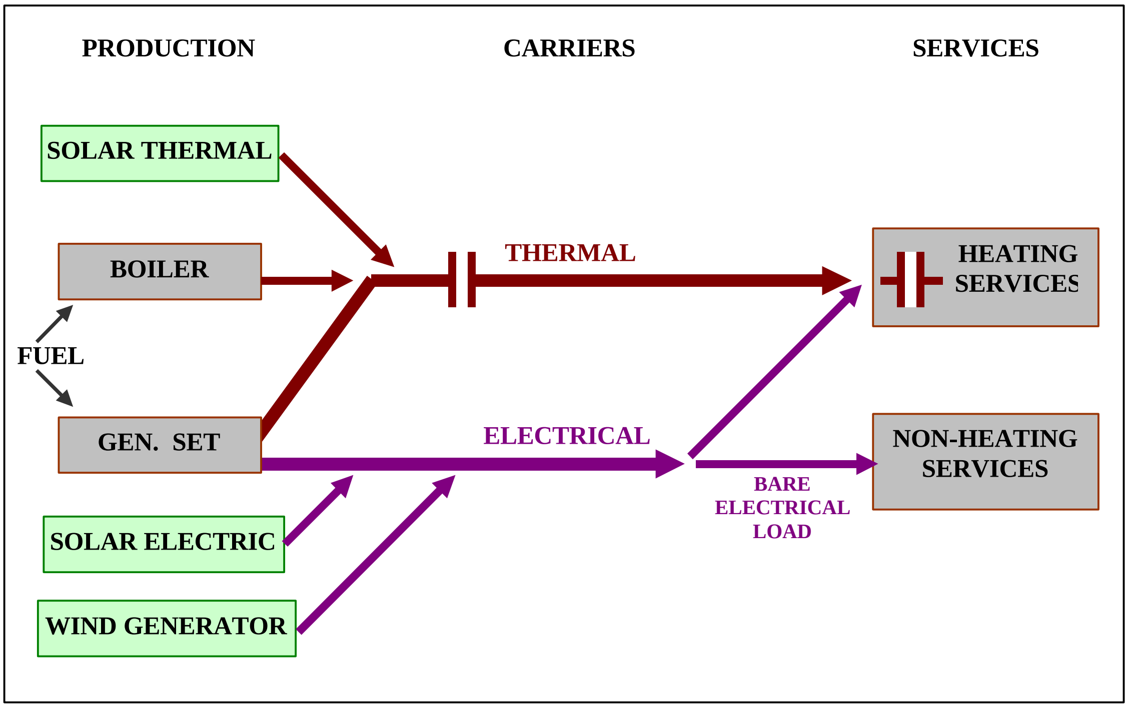

Figure 4: Hybrid system with diversion capability