BASELOAD AND INFLEXIBILITY

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1. Introduction

Much of the remaining advocacy in favour of current generation technology revolves around the ability of the current coal, gas and nuclear technologies to provide baseload power, which is portrayed to be essential. The opinion that baseload is an essential feature of power generation is even influencing the design of concentrating solar thermal (CST) technology, with the advent of the 'baseload' Torresal solar tower plant in Spain (Torresal, 2011).

The baseload + peaking generation strategy has been used for many decades, but is it the best way for the future? In this paper we show that baseload is not a necessity. It is, rather, a characteristic of low cost fossil, geothermal, and nuclear plants that are operated continuously to lower their relative capital expenditure. Running continuously, they are inflexible and unresponsive to load; it is said they are not 'dispatchable' . Other, more expensive, peaking technologies must carry out load matching and bear the heavy cost of such intermittent operation.

Are there non-baseload strategies that may be more suitable for renewable energy dominance of generation? We use the wind + solar strategy discussed in a companion paper at this conference (Mills and Cheng, 2011) as a example to illustrate that baseload generation is not essential to *either* renewable or fossil fuel generation, and that a broader and more insightful categorisation is now needed. We discuss other strategies that may arise as technology progresses.

2. The Baseload Paradigm

Baseload sources of power operate day and night for most of the year and allow reduced cost for coal and nuclear plants through better utilization of the power block. Many traditional engineers insist that baseload is an absolute requirement for a comprehensive and low cost system, complemented by intermediate peaking and fast peaking plants. There is a also great deal output from competitors to renewable energy saying that baseload is necessary and that renewables cannot do this.

Large companies and utilities supporting this view influence many politicians and ministers in most countries. A former Prime Minister of Australia, John Howard, said that "Solar is a nice, easy soft answer. There's this vague idea in the community that solar doesn't cost anything and it can solve the problem. It can't. It can't replace base load power generation by power stations." (ABC TV, 2007) .Not surprisingly, a Minister in his government agreed: "You cannot run a modern economy on wind farms and solar power. It's a pity that you can't, but you can't." (ABC TV, 2007). On March 11, 2009, Energy Secretary Steven Chu said to the the US Senate Budget Committee: "I believe nuclear power is an essential part of our energy mix. It provides clean baseload generation of electricity."(Chu, 2009).

There are many other examples of similar statements made in many countries, clearly agreeing with the views that (a) baseload is essential and (b) solar cannot produce baseload power. We disagree with both those propositions. Baseload is not essential. The solar tower in Spain shows that solar can generate baseload power. But we would also disagree with a third, increasingly common proposition: (c) that solar or wind *should* be producing baseload power.

3. Technical Discussion

Fig. 1 shows a schematic of the the traditional grid mix of technology. The dark coloured baseload component is nearly flat, except when load drops at night below the design baseload power output. The output need not be absolutely flat but should be working near maximum output most of the time to make best economic use of plant capital equipment.

The middle section is called 'intermediate peaking' and it describes a system that rises and falls slowly during the day and night to roughly match the daily rise and fall of electricity grid demand. It uses its equipment for fewer hours than baseload and thus has a higher kWh cost. In the USA, most NGCC plants are used for intermediate peaking. Interestingly, the pressures of a national spot market in electricity in Australia has caused coal plants designed for baseload to be pressed into service as intermediate peakers, but as with natural gas intermediate peaking, their capital utilisation declines with decreasing capacity factor and the system costs more to run with higher maintenance costs. However, this is usually repaid by being able to receive high spot market prices during peak periods.

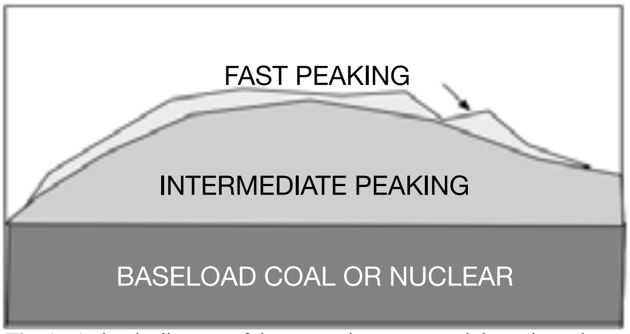

Fig. 1: A simple diagram of the generation types used throughout the day. In practice, baseload is not usually entirely constant and may slowly adapt to load, while fast reaction peaking technologies like gas turbines may turn on and off multiple times over 24 hours and can have a low CF of about 10%.

The top light coloured part of the diagram refers to fast peaking technologies such as gas turbines which are characterized by a low usage rate (low CF) and high kWh costs because of poor utilisation of capital and the necessity to use more expensive natural gas fuel. Hydroelectricity can also be used for fast peaking, and can be profitable because the limited water supply can be allocated to very highly priced peak load times but most fast peaking is done these days by gas turbines.

In (Mills and Cheng, 2011), the hour by hour USA electrical loads for a whole year (2006) were assembled from US government data, and the authored calculated that the entire electrical system could have been run without blackouts by a system composed entirely of highly variable sources - solar and wind. Absolutely no baseload was used in the simulation. Furthermore, the same system, enlarged appropriately for the increased load, could have run nearly the entire economy if thermal and transport loads were electrified. This part that could not be run with present wind and solar technology - virgin iron ore production and air transport - was difficult to access for technical reasons: iron ore reduction requires carbon as a reducing agent and aircraft need a combustable fuel[1]. Fig. 2 shows the continental US electricity load pattern derived from basic FERC data for 2006 (Mills and Cheng, 2001). Both intermediate and fast peaking conventional technologies are able to handle the big variations visible in the illustration, but fast peaking plants would be necessary for variations below an hour or so in time. A baseload plant fleet of 0.32 TW would just fit into this scenario, supplying almost everything below that output, but there was no such low cost baseload used in the matching simulation. Importantly whatever matches the baseload with the load must clearly deal with a highly variable load, and therefore can also match a *variable* inflexible fleet of generators instead. Importantly, if large numbers of generators are interconnected, the abruptness of variations will be much lessened due to averaging effects over the grid.

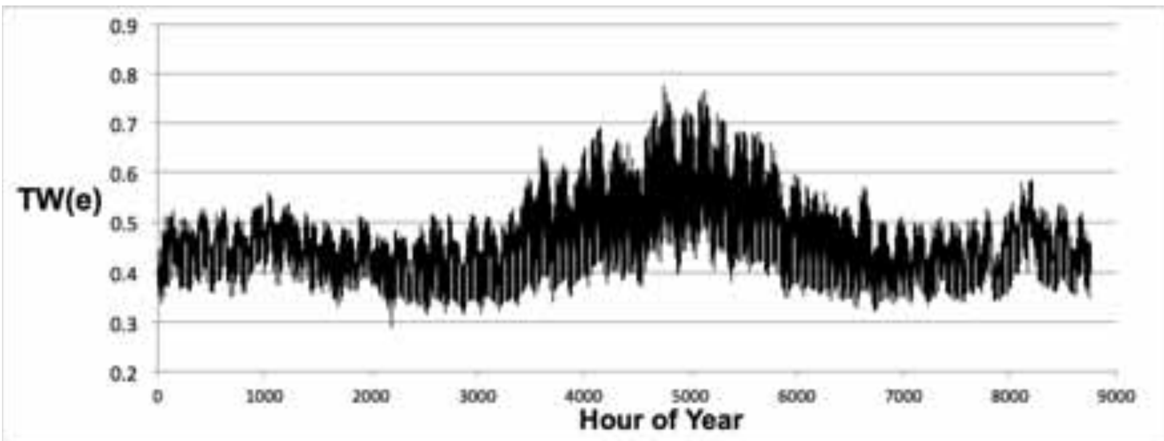

Fig. 2: Calculated continental US electricity load for 2006 in terms of TW(e) vs hour of the year. This is highly variable on a seasonal and daily basis, and clearly requires a flexible form of generation to match load with any inflexible generator output. It does not matter whether the inflexible output it itself variable or baseload. The dark region represents the variation in load that needs to be matched. The region below 0.32 TW(e) would be suitable for the operation of a fleet of baseload plants, the variations of intermediate peaking and fast peaking would have to match the dark regions in the diagram.

Fig. 3 shows the derived wind output for the USA in 2006 as used in Mills and Cheng. The low cost element is wind generation, but as is evident, wind is extremely variable and totally unlike the baseload characteristic in Fig.1. In spite of this, the solar component in the modeled energy mix was able to bridge the difference

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1 However, even these markets had the potential to be run by future technical processes using hydrogen fuel provided by electrolysis using electricity from the same solar and wind technologies. Hydrogen is an alternative reducing agent for iron ore and hydrogen can in principle be used as a fuel for aircraft.

between the wind output in Fig. 3 and the load in Figure 2, and achieved 100% reliability over the entire year modelled for some configurations. The solar generation was modelled as a concentrating solar thermal (CST) plant with thermal storage to achieve the required flexibility in output.

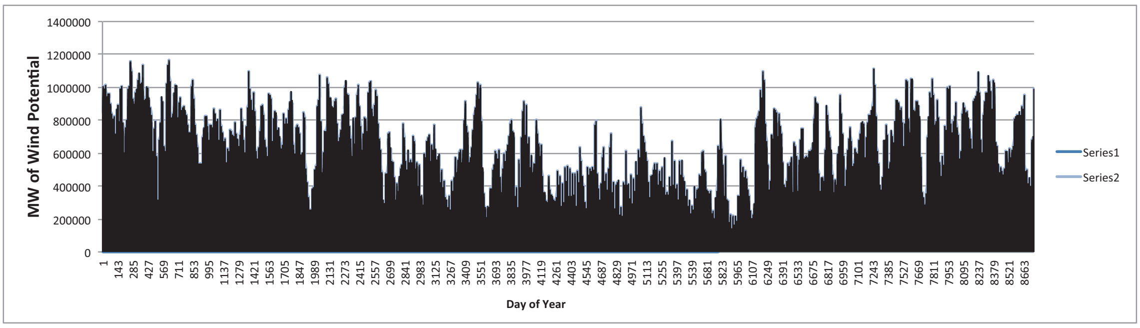

Fig. 3. Wind generation output for the USA in 2006. It can be seen that there are extremes of output between summer and winter. The wind output is prone to fluctuations between 0.067 and 1.02 TW(e).

Instead of Fig.1, we need a new and more general generation diagram. This is shown in Fig. 4, where neither component needs to be baseload, but the required load match still occurs. Clearly, a flat baseload output vs time characteristic is not a basic requirement for full grid coverage; the interface between the two generations types could be flat, but doesn't have to be. In other words, baseload operation is not essential. Rather, *baseload operation is a attribute of low cost fossil, geothermal and nuclear plants that are operated continuously to lower capital expenditure vs electricity generated.* In the wind/solar scenario, wind *does not share that attribute*, because it achieves its lowest cost as a variable output, not bearing the additional high cost of any steadying storage for its electrical output. In Fig. 4 the type of generation used is not mentioned; it could be renewable or non-renewable.

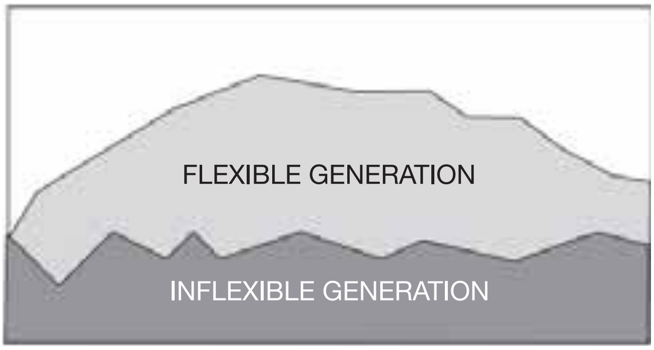

Fig. 4: A system with an inflexible source (variable or baseload) and a flexible dispatchable source (CST). Load-matching wind is not intrinsically more difficult than load-matching baseload to an unpredictable variable load like wind.

The ability to abandon baseload generation is not just some quirk of renewable energy. For example, natural gas combined cycle (NGCC) fossil fuel plants are highly adaptable and can provide either intermediate peaking or baseload generation without changing the design.. A whole generation network could be hypothetically be created from NGCC plants, each following the local grid load profile. No single plant would need to operate as 'baseload' in such a system. They could, and probably would, all satisfy their local grid load changes in parallel, seeking the highest prices in an electricity spot market. If we didn't care about the cost associated with natural gas fossil fuel, it would be sensible to run NGCC in this way for what currently comprises the fossil-fuelled intermediate peaking and baseload market network, because they would release about half the emissions of coal. Baseload + peaking is not an intrinsically bad system - it clearly works. It is simply a subcategory of a more general system, and there could be other systems.

A more insightful and broader categorization is needed so that people can think outside the present 'baseload box'. The authors believe that the most rational way to interpret the situation is to consider an *inflexible*, variable resource which cannot cary out peaking, paired with *flexible*, variable generation to provide a matched load for the total system. The main justification for the inflexible component is solely to introduce low cost energy into the generation mix, not to provide some essential technical foundation for generation. In this way of thinking, most (but not all!) complete systems would be composed of at least two main generation types, inflexible low cost components, and flexible higher cost components.

Possible inflexible technologies would currently include (a) coal, NGCC, nuclear, and geothermal operated as baseload; and (b) PV, CST, and wind operated without storage. Here, some new insights begin. We noted that the basic reason for introducing inflexible technology was electricity supply at low cost. Clearly, not all of these technologies are low cost, yet they are competing for the low cost inflexible generation market. Thinking within the new paradigm, high cost inflexible technologies are in deep trouble and might only survive through subsidy or re-inventing themselves. For example, should nuclear have a peaking capability? We would argue yes, if it is going to survive competition from wind, it needs to escape into the higher-priced flexible market. Additional exclusion criteria may apply to other competitors such as limited resource size for shallow geothermal or excessive pollution for coal.

Flexible technologies provide higher cost load matching and would include intermediate peaking NGCC, fast peaking gas turbines, peaking hydro, CST with thermal storage, and PV or wind with battery storage. Again these technologies all have pros and cons. Should CST be designed with baseload storage capability like that of Torresol? We would argue no, because this would make solar a more costly inflexible technology akin to nuclear. As our paper (Mills and Cheng, 2011) shows, lower storage levels than those necessary for baseload seem to be optimal for a flexible plant, and its main competitor in this sub-market, intermediate peaking NGCC, is higher priced than low-cost wind would be in the inflexible market.

The preceding paragraphs show that the continued obsession with baseload unmasks some inherent mismatches between technologies and markets, mismatches that are often sustained by inappropriate subsidy. It seems possible in principle to construct a load-matched system in principle using any inflexible system partnered with any flexible system, such as nuclear + CST, or wind + gas turbines. This is now easy to see; as an example, wind cannot 'pair' wind with nuclear alone because neither can adapt to load, seasonally or diurnally. These types of combinations are automatically excluded technically, even though most people would not think of nuclear and wind as direct competitors. However, to design an optimal system, it is also important to compare price with technologies that do exist within the same category. This is an important debate to have - should we be pursuing expensive inflexible technologies in a world with limited funds to invest in clean technology?

Table 1 shows estimated costs for technologies both current and emerging, but these are simple plant costs. In a future paper, we will make an approximate estimate for combined systems having flexible and inflexible components. and address variations in redundancy or overbuild, differences in inflexible to flexible generation ratios, differences in dumping, differences in fuel cost, and different relative tax concessions. That being said, it will be shown that

- an inflexible wind component is cheaper than an inflexible 2006 coal + nuclear component;
- the inflexible systems are usually larger than the flexible systems in terms of electrical output;
- the high cost of low CF combustion turbines raises the conventional flexible component cost well above that of NGCC alone;
- the cost range of a full CST/wind fleet overlaps with the cost range of a new conventional system.

Tab. 1: Flexible and Inflexible technologies in the near term. Most figures come from Lazard (2009) but these some have been altered with a known 13.6 cents per kWh cost for CST based on the Solar Reserve Tonopah plant (Solar Reserve, 2011), and a cost of 9 cents per kWh for NGCC peaking based on EIA figures adjusted to the Lazard capacity factor of 40%. The gas turbine figure of 23.5 cents is within the Lazard range and created from EAI figures adjusted for a 10% CF.

Operation	Flexible	Flexible	Flexible	Inflexible	Inflexible	Inflexible	Inflexible
Technology	CST	NGCC Int. Peaking	Gas Turbine Peaking	NGCC Baseload	Nuclear	Coal	Wind
Cost per MWh	13.6 Tonopah (2011)	EIA* 9.0 Lazard 10.2	Lazard 22.5-34.2 EIA* 23.5	6.6 DOE 7.4 Lazard	EIA 11.0-12.1 Lazard 10.7-13.8	6.7-9.5*	7.3 DOE (2010)

***EIA (2010) figures adjusted for capacity factor, coal CF not adjusted.**

There is also is a late-stage problem that emerges when we attempt to fully eliminate pollution. This is the high cost of grid blackout avoidance in a potential zero emissions scenario, as discussed in Mills and Cheng (2011) using only wind and solar. The cost of achieving the last few percent of load coverage is very high in redundant extra plant capital cost to avoid deficits and consequent blackouts. However, there are potential solutions discussed in that paper, some involving synthesis of hydrogen with redundant capacity. Use of under 2% of backup fuel can strongly reduce he capital cost of capacity required.

4. Concluding Comments

We are not the first to question the baseload paradigm. Jon Wellinghof is the Chairman of the US Federal Energy Regulatory Commission (FERC) and appointed to the FERC as a commissioner by then president Bush in 2006. He has said (Wellinghof, 2009) " *if you can shape your renewables, you don't need fossil fuel or nuclear plants to run all the time. And, in fact, most plants running all the time in your system are an impediment because they're very inflexible. You can't ramp up and ramp down a nuclear plant. And if you have instead the ability to ramp up and ramp down loads in ways that can shape the entire system, then the old concept of baseload becomes an anachronism.*"

Wind and CST with thermal storage seem to be prime candidates for the future global zero emissions race, with neither being configured as a baseload technology. Efforts to produce baseload solar are well meant but misplaced, as only 3 - 10 hours of storage time should be necessary, quite similar to the larger storage designs now being planned by Abengoa and Solar Reserve. It should be noted that thermal storage is dropping in cost (BIPC, 2011) and if low enough in cost will actually reduce the cost per kWh of CST, because the turbine cost can be reduced more than the cost of storage added. This is not the case with PV or wind; storage adds to kWh cost in those cases because there is no internal technology cost offset.

As we carefully noted earlier, not all generation systems need be composed of simple combinations of inflexible and flexible systems. Very low cost electrical storage, now being researched heavily because of the rise of electric cars, could be a game-changer, particularly if PV fields drop well below the cost of CST fields. If a flexible system becomes cheaper than an inflexible, then the former is all you need. In the past New Zealand and Norway had virtually 100% hydro - a flexible and clean system - as the cheapest option. In the future, low cost backup battery storage may lead to the demise of inflexible generation. In such a system, each flexible PV, wind and CST generator and its battery would be an intelligent, independent node in a spot market distributed not unlike the internet, receiving price signals from the grid, and making automated offers and sales in return. This would be the ultimate sustainable system, very large, very clean, and resilient to damage - if the software doesn't get hacked.

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