REPLACING INTERMITTENT RENEWABLE CAPACITY IN THE 2010 IRP WITH CSP: EFFECT ON COAL FIRED POWER STATION CAPACITY FACTORS IN 2030.

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Abstract

This paper investigates the effect adding either photovoltaic power (PV) stations or concentrating solar power (CSP) stations equivalent in capacity to 10% of the installed conventional plant to the South African power supply, as envisioned in the 2010 Integrated Resource Plan (IRP) for the year 2010, has on the conventional power plants already in the system. This was done by modelling the conventional system and the PV plant on an hourly basis. The exercise was then repeated replacing the PV stations with CSP stations that were run as peaking power stations. The paper shows that adding PV reduces the capacity at which conventional stations are run during the day, but does not affect the capacity at which they are required to run during peak demand. Adding CSP was shown to reduce the capacity at which conventional stations were run during peak demand periods, effectively increasing the available reserve margin.

Keywords: Capacity Factor, Reserve Margin, PV, CSP.

1. Introduction

According to the current IRP 17.6 GW of installed intermittent renewable generating capacity should be built by 2030 along with another 1.2 GW of CSP generating capacity. Of the intermittent renewable generating capacity 8.4 GW will consist of PV which corresponds to about 10% of the planned total system capacity [1].

When the IRP was developed the various renewable energy technologies were evaluated mainly on cost per MWhr produced and the largest share of the renewable mix was allocated to intermittent technologies. As PV will only contribute power during daylight hours, not during the periods of peak demand in the evening, all PV capacity was added on top of the conventional capacity that was planned to meet projected demand. However, introducing additional generating capacity will lower the capacity factors at which the rest of the system will operate. This paper aims to show the way in which introducing either PV or CSP capacity equivalent to 10% of installed capacity will affect the rest of the system.

In order to achieve this end the conventional system and the power produced by the two renewable technologies were modelled on an hourly basis. An overview of these models can be seen in section 2.

In order to isolate the effects of the two types of renewable energy being studied the demand and generating capacity detailed for 2010 in the IRP were used as base case. The results of running the conventional system model with these inputs are shown and discussed in section 3. The effects of adding PV to the base case and the effects of adding CSP are shown and discussed in sections 4 and 5 respectively.

In conclusion the results shown in section 3, 4 and 5 are summarized in section 6.

2. System and renewable energy models

The model is made up of two parts. The first part models the conventional South African power system. The conventional system model is discussed in section 2.1. The second part models the power that may be produced in the future by independent power producers (IPPs) utilizing either PV or CSP. The modelling of CSP is discussed in section 2.2 and the modelling of PV is discussed in section 2.3.

2.1. Conventional system model

The conventional generating network was modeled using an hourly demand curve that was based on the 2010 IRP demand curve. The conventional generating units were ramped up and down to meet the curve and satisfy demand. All conventional available generating units in the system were modeled on an hourly basis. The model takes as input the maximum capacity, minimum capacity and ramp rate of each unit.

2.1.1. Types of plant

The conventional generating units are divided into base load units and peaking units. These types of units are handled in different manners. Coal-fired and nuclear plants are seen as base load units. They are deployed first in order to meet demand and are usually operated at loads ranging between 50% and 100% of their full capacity. Due to the unique nature of nuclear plants, nuclear units are never run below 80% capacity. Because South Africa only has one nuclear power station this does not greatly affect the overall capacity at which the base load units are run.

Peaking units are only deployed in cases where the base load units are incapable of meeting demand. This happened when the base load units are already running at their full capacity and more power is required or when the base load units cannot ramp up power production fast enough due to limitations on the rate at which they can pick up load.

The model deals with three different types of peaking unit: hydro power stations, pumped storage stations and open cycle gas turbines (OCGT).

In the case of hydro power stations and pumped storage stations the number of hours that each of these unit types can operate during any given day are limited. Other countries may run their hydro power stations as base load stations, but South Africa is a water scarce country. Hydro stations are generally used to balance load distribution over the country [2]. In the model hydro power stations are only loaded in cases where not loading them would lead to load shedding. Hydro power stations are further limited to four hours of full load operation per day.

Pumped storage stations are limited in the number of operating hours during which they can run full load due to the fact that they must be loaded (by having water pumped back up to the upper reserved dam) during every 24-hour cycle. In the model pumped storage stations are limited to eight hours of full load operation of which four hours are reserved for evening peak operation.

OCGT units do not have the same limitations as hydro power stations and pumped storage stations do, but they are the most expensive form of power in the conventional system. In order to minimize cost pumped storage units are always loaded first when available and only in cases where there is still a shortfall after the pumped storage units are at full load does the model run the OCGT units.

2.1.2. Inputs

The conventional system model has four important inputs: information on the different operating units in the system, a list of planned outages, a list of unplanned outages and the demand curve.

Information on the size and type of different operating units was taken from the appendages of the IRP [1]. The approximately 2300 MW of generating capacity that is not under Eskom control, and of which the unit size and unit type was not specified, where modelled as small (100 MW to 200 MW nameplate capacity) coal-fired power plant. Further information on the Eskom controlled plant was taken from the Eskom website [2]. It should be noted that these units might not all have actually run during 2010, but the model assumes that the schedule detailed in the 2010 IRP was followed.

Planned outages were distributed between the different operating units. For the base load plant 60 day, 30 day and ten-day outages were scheduled. A few shorter outages were also included in order to make up a total planned outage schedule that would correspond to 7% of yearly base load generating capacity. For the hydro and pumped storage plants planned outages of varying length were scheduled to correspond to 5% of the yearly generating capacity. No planned outages were scheduled for the OCGT units as Eskom reports a

99% availability for them over the past three years [2]. All planned outages were set to start on the first day of the year and model then deferred them until they could be allocated.

The unscheduled outage list was set up to have short outages of random length and start date that corresponded to a total of 3% of the total generating capacity for each type of unit. In order to prevent any one single unplanned outage from having undue impact on the overall results five different unscheduled outage lists were used and the results were averaged.

The planed and unplanned outage durations were set up to meet Eskom set goals on planned and unplanned outages, but it should once again be noted that these do not necessarily correspond to actual unit availability during 2010.

The input demand curve for the base case was generated by taking an existing demand curve and amplifying it to meet both the maximum demand and yearly demand that was projected for 2010 in the IRP.

2.1.2. Outages

The model can handle both planned and unplanned outages. In the case of planned outages the outages can be deferred in cases where insufficient capacity is available on the system to meet projected demand. When a planned outage becomes due it is added to the outage list. The model goes through the outage list once a day and determines whether there is sufficient capacity on the system for each outage to be run without impacting on security of supply. That determination is made by comparing the available capacity to the projected demand plus 15%. If there is sufficient capacity the outage is removed from the outage list and the unit is made unavailable for a number of hours that correspond to the length of the outage. The outage list prioritizes outages in terms of when they were scheduled to start and their position on the outage last. The only exception is in the case of nuclear units. Nuclear outages are moved to the top priority position when they become due.

After the allocation of scheduled outages has been determined the model goes through the unplanned outage list. If any unplanned outages are due, the corresponding units are made unavailable to the model for the number of hours that the outage is set to run.

2.1.3. Validation

Figure 1 shows that the model of the conventional system increases and decreases the power delivered by the units being modelled in such a manner as to match the total power produced to the demand curve. The curves cover 192 hours of operation.

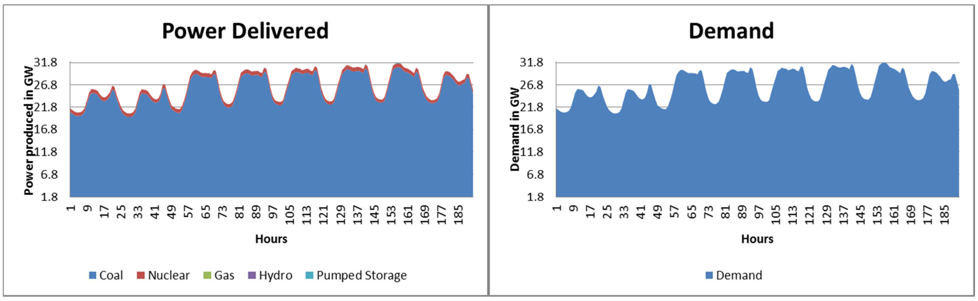

Fig. 1. Conventional system model validation

2.2. CSP model

The CSP plants were modelled as peaking plant with solar multiples of 3 and 12 hours of storage. A simple model that takes DNI and weather information as inputs and calculates the power output of a power tower CSP plant using estimated efficiencies was used to calculate the hourly station send out. In order to run the units as peaking power stations, power production was deferred on each day until sufficient energy had been stored for the plants to run for the four hours of evening peak.

2.2.1. Inputs

The hourly DNI and ambient temperature for 16 different locations as well as the longitude and latitude of the different locations were used as inputs to the model. Wind speeds of 2 m/s were assumed at all times.

2.2.2. Outages

The output power of each plant was disregarded on a rotating basis over the course of the year for a period of 22 days each in order to simulate planned outages. No unplanned outages were simulated for the CSP plant.

2.2.3. Validation

SANREL's system advisor model (SAM) was used to validate the CSP model. SAM does not allow for the CSP plant to run as peaking power stations so the CSP model was run without the requirement to store power for peak consumption during the validation process. The CSP model results were within 10 MW on a 100MW nameplate unit of the SAM results 77% of the time. SAM used input data with the actual wind speed information included in the validation data set while the CSP model used an assumed wind speed of 2 m/s.

2.3. PV model

The PV plants were modelled as stationary units, single axis tracking units and two axis tracking units and the results were averaged.

2.3.1. Inputs

Hourly DNI, GHI, DHI and ambient temperature information for the same 16 locations, which were used to model the CSP units, as well as their longitude and latitude were used as inputs to the model. Once again a wind speed of 2 m/s was assumed.

2.3.2. Outages

No outages were modelled for the PV plants as PV does not have planned outages and no unplanned outages were scheduled for either PV or CSP.

2.3.3. Validation

SAM was once again used for validation. The PV model results were within 10 MW, for a 100 MW nameplate plant, of the SAM results 69% of the time.

2.4. Interaction between models

For all cases where renewable energy production was simulated, the produced energy was subtracted from the base case demand curve before the curve was inputted into the conventional system model. The conventional model still used the base case demand curve as the projected demand to determine whether a unit can go on planned outage or not.

3. Base case: The conventional system

The base case derives from running the conventional system model without any inputs from renewable power sources.

3.1. Capacity at which units are run

Figure 2 shows the capacities at which the different types of plants were run expressed as a percentage of the full generating capacity of the all units of that type that were not on outage at the time. This is shown for 10 days during the winter.

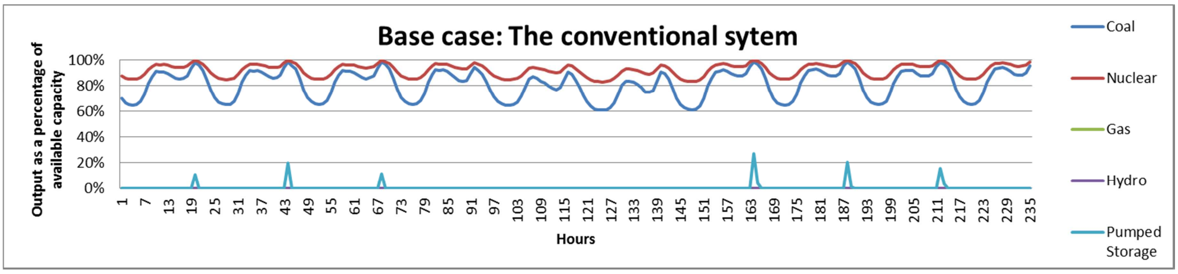

Fig. 2. Plant capacities for base case

It is important to note that the graph does not show capacity factors as these would include data from units that are on outage. It can be seen that the coal plant cycles between running at 60% and 100% of full available capacity. The ideal would be for the coal plant to operate between 80% and 100% of full available capacity because that is where production is most efficient and thus least expensive.

3.2 Reserve margin and outages

The model will defer outages in order to maintain a reserve margin of 15%. In the base case scenario no outages were deferred past the end of the year. This means that all planned outages were executed while a 15% reserve margin was maintained at all times. The model also used very little peaking power and almost no gas and hydropower was utilized.

This does not correspond well to known system behaviour during 2010. The reason for the disparity can probably be ascribed to two factors: the percentages of planned and unplanned outages that were modelled were probably lower than the actual percentage of planned and unplanned outages experienced during 2010. Additionally the conventional system model allows planned outages to be deferred until sufficient margin is available. However, in reality this cannot always be done, as some planned outages cannot be deferred indefinitely, but have to take place within a set period of time. During these periods less than 15% reserve margin would be available and more peaking power plant capacity would be utilized.

4. Effect of adding PV equivalent to 10% of total system capacity

The summed outputs of the 16 PV plants were amplified to provide PV capacity that corresponds to 10% of the total system capacity. This corresponds to the percentage of PV capacity that will be installed by 2030 according to the IRP.

4.1. Effect on the capacity at which base load units are run

Figure 3 shows the capacities at which the conventional plants were being run, for the same 10 days as shown for the base case, when PV has been added to the system. Once again note that the graph shows only the capacity at which running units were utilized and data from unavailable units was not included in the calculation.

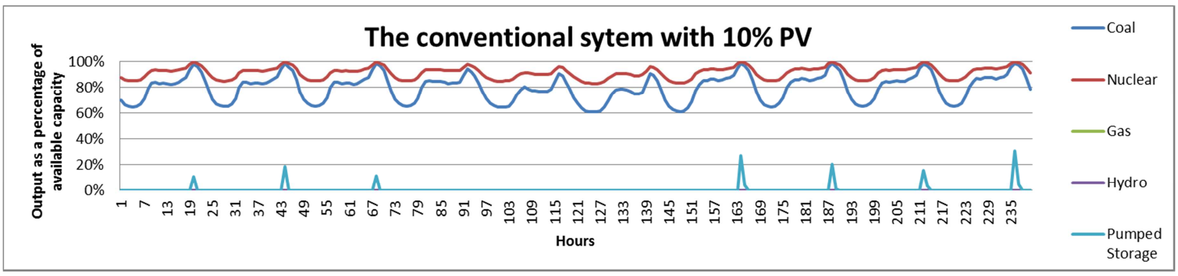

Fig. 3. Plant capacities with 10% PV

By comparing this to the base case shown in 3.1 it can be seen that adding 10% PV capacity to the system depressed the capacity at which the coal and nuclear plant were run during part of the day, but for the most part it did not drop these capacities below 80% during the periods when the plants were affected. It can also clearly be seen that the PV plant did not affect the capacity of the conventional units during peak demand periods. Coal units were still seen to operate in a range between 60% and 100% of the available full load capacity.

4.2 Effect on reserve margin and outages

Adding the PV to the system did not affect either the reserve margin or the number of outages that could be scheduled. The amount of peaking power used was only slightly affected, as they generally were not required to run during the periods where power from PV units were available. In this scenario 211.8 GWhr of energy was produced by peaking plant during the year compared to the 234.37 GWhr that was produced in the base case scenario.

5. Effect of adding CSP equivalent to 10% of total system capacity

As with the PV plant, the CSP plant outputs for the 16 different locations were summed and the result was amplified to correspond to an installed CSP capacity that corresponded to 10% of the total system capacity. In the case of CSP the model was first run exactly as the PV model was run and then the model was run with double the number of planned outages and the conventional system model was allowed to assume that 50% of the installed CSP capacity would be available during evening peak.

5.1. Effect on the capacity at which base load units are run

Figure 4 shows the capacities achieved by the conventional units when the CSP plant ran as peaking plant, but the conventional system did not take CSP production into account when planning outages.

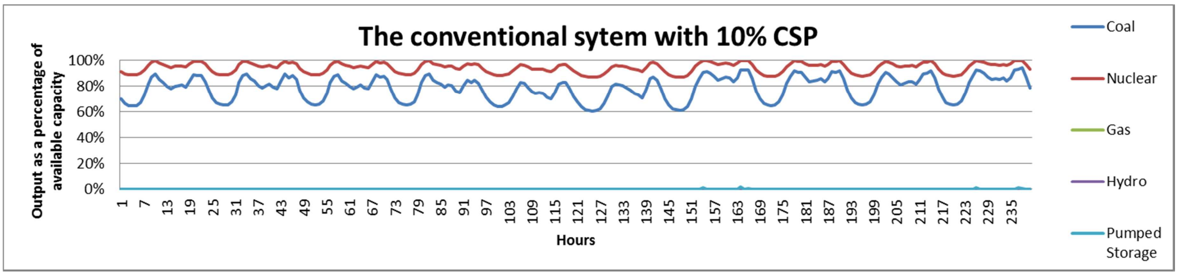

Fig. 4. Plant capacities with 10% CSP

From the figure it can be seen that production by other peaking plant was suppressed almost entirely and that production by the coal plant ranged between 60% and 90% of full capacity. In this scenario it can be seen that introducing CSP as peaking plant reduces the number of coal plants that are required by the system to ensure continuity of supply, as none of the running plants were used at full capacity.

This was confirmed by the second run of the model where the conventional model assumes 50% availability of installed CSP capacity when planning outages. For this run the number of planned outages was doubled. Figure 5 shows the results for the same 10 days.

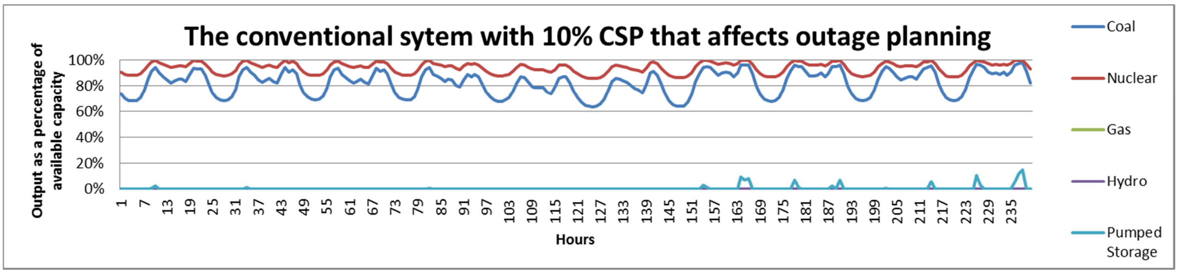

Fig. 5. Plant capacities when 10% CSP is added and allowed to affect outage planning

It can be seen that the coal plants in the second run of the model run at higher capacities. This happens in effect due to the fact that the conventional model can now schedule more outages. Thus, fewer units were running and they were running at higher loads. This means the units in question would also run at higher efficiencies and the overall cost of the power produced by the running units would drop due to lower fuel consumption.

It can thus be seen that adding CSP plants that are run as peaking stations increases the available margin for outages, or in cases where no additional margin is required, reduces the need to build new coal plant.

5.2 Effect on reserve margin and outages

Adding 10% CSP and allowing the system to assume that half of this was available during evening peak effectively doubled the number of outages that could be executed without affecting reserve margin. Running these CSP plant as peaking power stations also reduced the need for other peaking stations to supply power.

When the conventional system model was not allowed to take CSP capacity into account when planning outages the power produced by the other peaking plant was reduced to 10.16 GWhr and in the second case where the number of outages run was doubled the power produced by peaking plant was still reduced from the base case production of 234.37 GWhr to 163.20 GWhr.

6. Conclusion

Replacing the percentage capacity allocated to PV by 2030 in the 2010 IRP with CSP that is configured to run as peaking plant serves to illustrate that while adding PV to the system does reduce the consumption of coal, adding CSP reduces both the consumption of coal and the need to build new coal capacity. The addition of CSP peaking plant to the system allows for base load units to be run more efficiently while reducing the need for other peaking power stations to run. PV does not offer these advantages.

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References

[1] Integrated resource plan for electricity. 2011. South African Government Gazette, 6 May

[2] [S.a.]. [Online]. Available: www.eskom.co.za/c/12/power-stations [2013, July 15].