REVIEW OF LARGE INDEPENDENT ELECTRICITY GRID SYSTEMS' TRANSITION TO RENEWABLE GENERATION AND ITS RELEVANCE FOR SOUTH AFRICA

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Abstract

To meet its commitments to reduce greenhouse gas emissions from its power generation system, South Africa is planning to increase the percentage of generation from renewable resources and reduce the share coming from coal fired generation. To be the most efficient at achieving this goal, it is important to learn from other countries' experiences. Looking at international examples of large island systems, which are isolated from integrated networks, South Africa can see what has been done within systems that face the same constraint from their size. Reviewing the relevant systems around the world, it is apparent that dispatchable gas generation is the common ingredient that each of these systems has and the major factor that determines a system's ability to integrate significant percentages of variable generation from renewable sources. These systems have been shown to incorporate large percentages of variable generation due to the dispatchable power they are able to employ as needed. From this review, it is concluded that South Africa must incorporate a significant share of dispatchable power if it is to achieve its desired goal of reduced of greenhouse gas emissions.

Keywords: Renewable Energy, Dispatchable Power, Natural Gas, Large island systems

1. Introduction

Almost every country in the world has committed through the Paris Accord to reduce their production of greenhouse gases (GHG) to minimize the impact on climate change. In this Accord, each country has made its own commitments to develop renewable energy production sources to minimize the amount of greenhouse gases that are produced with burning fossil fuels. For South Africa, this commitment includes a peak GHG emissions by 2025 and decrease going forward, by reducing the production of electricity from "inefficient" coal generation, as stated in the South Africa "Intended Nationally Determined Contribution" [1]. Many countries have made great strides in the development of renewable sources. To aid in meeting its target commitments, there is an opportunity for South Africa to learn from these experiences to determine what is relevant and what lessons can be learned from them. As many countries are part of large integrated networks, these may not be the most appropriate models. A subset of international examples, the "large island" countries are a better model to be used as they must resolve similar problems to the South African grid without relying on a large network. While South Africa is connected into the Southern Africa Power Pool (SAPP), South Africa alone provides and uses about 80% of the capacity and generation. The overall size of the pool, with a total installed capacity of about 60 GW and the lack of significant inter-regional transmission systems leaves South Africa effectively in an isolated network with or without considering the SAPP [2]. There are a number of large island systems where significant renewable energy implementation is taking place. From the experiences of these countries, South Africa can learn lessons to apply to the local situation.

2. Background

There has been a debate around the world for many years about what percentage of renewable power generation can be utilized before the grid becomes unable to meet its requirements. As time has passed, the numbers have continually increased, to the point now where the debate is on whether 100 % renewables is realistic or not [3][4]. However, as all of the expected numbers are quite high, more relevant than the absolute value that a grid can handle are the conditions that must exist for the maximum percentage to be achieved. On this view, there seems to be more consensus that dispatchable power is a requirement for large scale renewable implementation [4].

Currently, the most economical dispatchable power comes from natural gas fired generation. Bloomberg New Energy Finance stated in their 2017 forecast on renewable energy that “Gas is a transition fuel, but not in the way most people think. [….] [G]as plants will mainly act as one of the flexible technologies needed to help meet peaks and provide system stability” [5]. While there has been progress in meeting the time-shift needs of a renewable based generation system with concentrating solar power (CSP) and battery storage systems where energy can be stored until the time of day when it is needed, there has been less progress on meeting the longer term dispatchable needs [6]. For any type of stored energy system, whether it is batteries, compressed air, pumped hydro or other technologies, the energy that can be provided by the backup system is limited to the amount of storage. For most systems, this is measured in hours.

Natural gas dispatchable power systems provide the ability to meet renewable energy shortages, whether it is for days, weeks or longer dependent on seasonal or unusual weather conditions. As it is unclear how much backup power might be needed in the worst-case scenarios, most utility systems take the conservative view of having enough dispatchable power capacity available to completely replace the renewable supply as needed [7].

3. International studies

In a presentation to the Electric Reliability Council of Texas (ERCOT – the network operator) in Texas on 7 September 2017, Dr. Eugene Preston discussed the possibility of 100% renewable sourced energy and concluded that; “If you miss a day of production in renewables you have to fire up the gas generators to fill in the demand. In fact, you have to keep most of your fossil fuel capacity in standby to fill in when renewables fail to produce enough energy”[7].

In a blog written in January 2017, the German economist Heiner Flassbeck, indicated that a period of extremely low solar and wind power generation in December 2016 showed that Germany could never completely rely on renewable energy, regardless of how much new capacity will be built. He concluded that Germany must maintain at least 50 GW of fossil fuelled dispatchable generation capability to ensure power supply [8].

In a 2016 review of the renewable energy implementation in 26 OECD countries between 1990 and 2013, E. Verdolini, F. Vona and D. Popp concluded that: ”A 1% percent increase in the share of fast-reacting fossil generation capacity is associated with a 0.88 % percent increase in renewable in the long run”. Gas driven dispatchable generation is a common thread in countries with high renewable energy production [9].

It is helpful to read about countries such as Denmark with large percentages of renewable generation, exceeding 100% of their need at times. However, many of these examples show that one of the major elements of the large-scale renewables usage for a region or country is access to a large network where their shortfalls and excesses can be balanced. As concluded in the review of the Denmark example, “market based power exchange with neighbouring countries is the most important tool for dealing with high shares of wind power in Denmark”[10]. To this end, most of Europe is interconnected and North America is interconnected into two major systems. China has a large network with a capacity rivalling that of all of Europe. Each of these interconnected systems allows high regional variable energy sources to be balanced with other supplies. There is a question therefore of the relevance of these examples to the situation of South Africa where there is no large network to back up the system.

4. Large island systems

Relevant examples for South Africa should be those regions and countries that have grids of similar sizes that are not connected into large networks. The South African electric grid produces about 250 TWh per year [11]. There are a number of regions and countries with isolated grids of similar size. Those considered for this study are (a) Australia – specifically, the east coast states (b) Taiwan, (c) Spain, (d) the UK system, and (e) Texas. Each of these grid systems has experiences with integrating renewables into the network and dispatchable power to provide the backup to the variable renewable sources.

Installed capacities and generation values for each of these systems are shown in table 1. The breakdown used is “firm” for those sources of generation, mostly coal and nuclear, that are primarily used to supply the base load capacity and generation for the system. Gas sourced generation is noted separately for each system, as well as that sourced from wind and solar generation. Hydro capacity includes primary hydro systems as well as pumped hydro. From the generation values, pumped hydro is netted out as it is considered only as storage, not a net generation source. Comparing the size of installed wind and solar capacity to the gas capacity gives a good indication for each system of the ability thereof to cover the variable renewable generation as well as room for growth of the renewable input. As can be seen from table 1, while all of the other large island systems have a significant percentage of dispatchable gas generation, South Africa has almost no dispatchable capacity. This is a challenge for implementation of any scale of renewable generation.

		Australia	Taiwan	Spain	U.K.	Texas	South Africa
Capacity	Total	54	49	105	89	105	49
(GW)	Firm	32	22	37	32	26	39
	Gas	10	20	29	34	52	4
	Pumped Hydro	1	3	8	3	0	3
	Wind / Solar	11	4	30	20	27	3
Annual Average Generation Rate	Total	29	30	28	38	55	26
(GW)	Firm	21	17	16	17	18	25
	Gas	6	11	5	16	30	1
	Pumped Hydro	0	0	0	0	0	0
	Wind / Solar	2	1	7	5	7	1
Capacity Percent	Firm	59%	45%	36%	36%	25%	80%
(% of capacity)	Gas	18%	40%	28%	38%	50%	8%
	Pumped Hydro	2%	5%	8%	3%	0%	6%
	Wind / Solar	20%	9%	29%	22%	25%	7%
Generation Percent	Firm	73%	58%	56%	43%	32%	95%
(% of generation)	Gas	20%	37%	18%	43%	54%	2%
	Pumped Hydro	0%	0%	0%	0%	0%	0%
	Wind / Solar	7%	5%	25%	14%	13%	3%

Table 1 - Installed Capacities and Generation for Large Island Systems [1]

5. Renewable energy in the large island systems

It is important to study the experiences of these countries individually to see common issues and those that are local and handled differently in the various countries.

5.1. Eastern Australia

Australia, at about 200 TWh per year, is the smallest network considered. The grid, operated by the Australia Energy Marketing Organization (AEMO), covers the five Eastern Australian states, Queensland, New South Wales (including the Australian Capital Territory), South Australia, Victoria, and Tasmania. Western Australia and the Northern Territory are not connected due to the distance between the networks.

The majority of generation has traditionally been coal fired. Coal still provides most of the base load generation as shown in figure 1, producing 63% of the overall output from 42% of the installed capacity with a utilization factor of 82%. Overall, the utilization factor of all installed capacity is 54% [12][13].

While wind power is the largest utility scale renewable source of generation in Australia, the major growth of renewable energy has been with household PV systems, with 13% of the total installed generation capacity provided by rooftop PV. It is expected by the grid operator that distributed power generation will grow from 5 GW to over 20 GW of installed rooftop PV within their 20 year planning period of 2017-2037 [14].

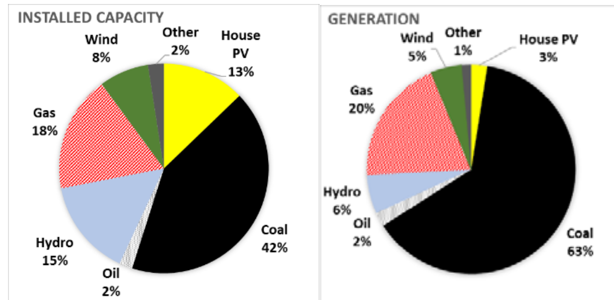

Figure 1 - Eastern Australia Installed Capacity and Generation [12][13]

5.2. Spain

Spain, with its network effectively isolated from the rest of Europe, was one of the early adaptor countries for both solar energy and wind power. In this early growth, from 2003 through 2012, Spain installed 23 GW of wind capacity and 6.9 GW of PV and CSP production. At the same time, the country built 25 GW of gas powered peaking plants [15]. With this large growth in capacity and the lack of economic growth since the recession of 2008, Spain has ended up with reserve capacity of over 350% of nominal average need. The entire system is underutilized, with an overall utilization factor of 29%. Growth in renewable energy came to a halt in 2012 and the only current growth is in pumped storage [16]. The grid operator has proposed to close down some of the installed coal generation capacity, but this has been resisted by the government on the basis of protecting the local fuel supply to these generators [16].

As seen in figure 2, co-generation, nuclear and coal-fired generation provide the base load in Spain, with 23% of the installed capacity and 49% of the generation. Gas and hydro, both pumped hydro and straight hydro power, provide the flexible generation for the grid to handle the variable generation from the wind and solar systems [17].

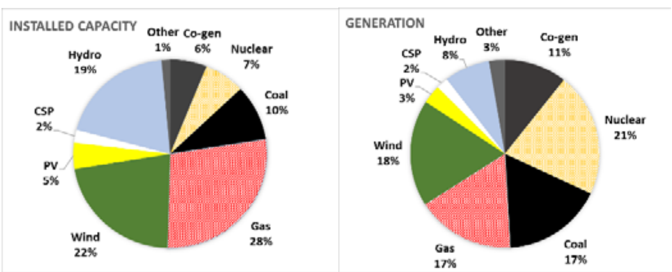

Figure 2 - Spain Installed Capacity and Generation[17]

[1] Data – Australia [12][13], Spain [17][25], Taiwan [18], UK [26], Texas [23], South Africa [11][29]

5.3. Taiwan

Taiwan, with a network supplying about 250 TWh per year has no indigenous fuel supply [18]. Imported gas, in the form of LNG, supplies most flexibility. Taiwan has been a late adaptor to renewable energy. In 2010, the government began actively developing renewable generation and has plans in place to bring the installed capacity of renewables up to 27 GW, to generate 20% of the total supply, by 2025 [19][20]. The government also plans to phase out nuclear generation by that time. These factors will require more dispatchability from the portion of gas fired generation [18].

Currently, nuclear and coal provide the base load generation with 46% of the installed capacity and 59% of the generation as shown in figure 3. Gas and hydro provide the flexible generation in the system.

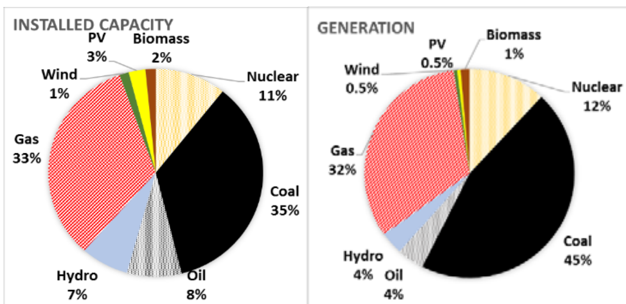

Figure 3 - Taiwan Installed Capacity and Generation [18]

5.4. United Kingdom

The United Kingdom was the original coal-based power system and started the industrial revolution based on its coal-fired generation. However, the government has made significant efforts to reduce the country's dependency on coal. The generation from coal dropped from 16% in 2015 to 9% in 2016, effectively completely replaced by natural gas [21]. As shown in figure 4, coal now only represents about 16% of the overall capacity and about 9% of the generation. Gas now makes up 39% of the capacity and 43% of the generation. In addition, the UK has about 6% of its generation capacity in bio-mass systems that provide a portion of the base load, providing 9% of the overall generation.

With its far north latitude, the solar resource in the country is not as good as some of the other countries reviewed. However, there is a large available resource of onshore and offshore wind. The UK has about 8 GW of installed wind capacity, mostly onshore, and 12 GW of installed grid connected PV capacity as of 2016 (BEIS, 2017 table 5.12) [21]. These resources make up the majority of the installed renewable capacity.

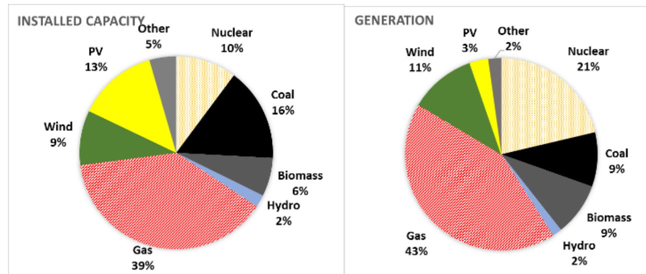

Figure 4 - UK Installed Capacity and Generation [21]

5.5. Texas

Texas is known as the oil and gas capital of the USA and the majority of its electric generation is from natural gas. However, it also has the largest wind powered generation of any US state and this provides the ERCOT grid system with the highest renewable generation percentage of any of the North American grids. The Texas grid is an island grid by choice, keeping the limits of the system within state borders to avoid federal involvement. Texas has excellent wind and solar resources. The state has taken a neutral view of the renewable generation systems to be developed and wind has been dominant to date based on price. ERCOT reported that they expect all of their growth in generation in the next two decades to come from utility scale PV systems [22]. There is no state-wide mandate for tie-in of household PV systems and there has been minimal development in that area and no major take off is expected.

As shown in figure 5, coal and nuclear provide the base load for the system with 25% of the installed capacity and 32% of the generation. Gas provides all the flexibility needed for the variability of the wind resource [23][24].

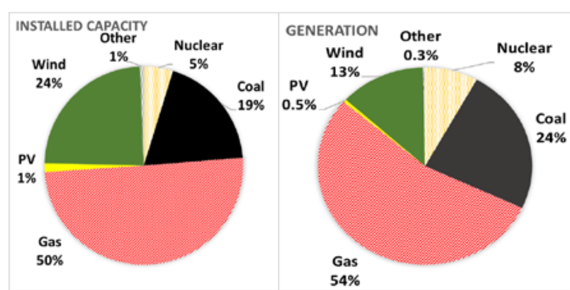

Figure 5 - Texas Installed Capacity and Generation [23][24]

6. Variable generation issues

In the next examples, the variability of the renewable generation provided for three of the networks, Spain, UK and Texas, is shown over the ten-day period of 1-10 January 2018. This period was arbitrarily chosen to show the nominal range of the system with current generation capacity over a short period of days. The days within this range with the largest and smallest contribution from renewable sources are shown in the following figures. These examples do not represent the entire range of generation from any of the systems, however, they do show the wide variations representative of expected values. Australia and Taiwan, with smaller percentages of renewable production, do not have the daily production rates in the public domain.

6.1. Spain

With nearly 30 GW of installed wind and solar generation capacity and an annual average overall generation of about 28 GWh equivalent, Spain has the ability to generate a large percentage of its required power from renewable resources. As the energy from wind and solar resources is considered the priority supply, much of the remaining generation capacity must be utilized as mid-merit or peaking. The only portion of the generation system used as base load is the nuclear power sector (8 GW installed capacity), which is used at about 80 % utilization. Co-generation is utilized as a required input when available and the coal-fired generation is only utilized at about 40%.

As seen in figures 6 and 7, during the period of 1 to 10 January 2018, the percentage of power generated from wind and solar resources varied from providing 7% to 44% of the load. As can be seen from figures 8 and 9, this variability of generation pushed the use of dispatchable generation to the limit of the systems, with effectively all dispatchable power shut down on 8 January 2018 to accommodate the large renewable generation that day.

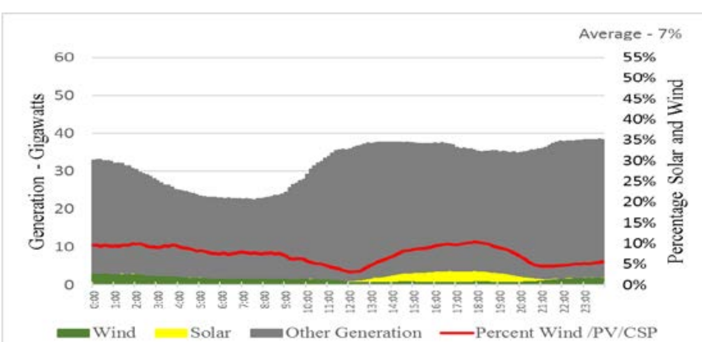

Figure 6 - Spanish Renewable Generation - 8 January 2018 [25]

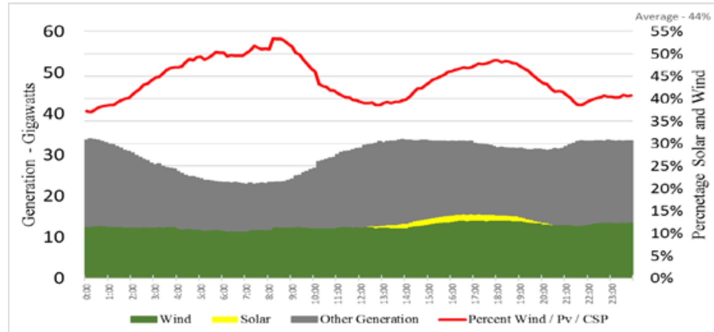

Figure 7 - Spanish Renewable Generation - 4 January 2018 [25]

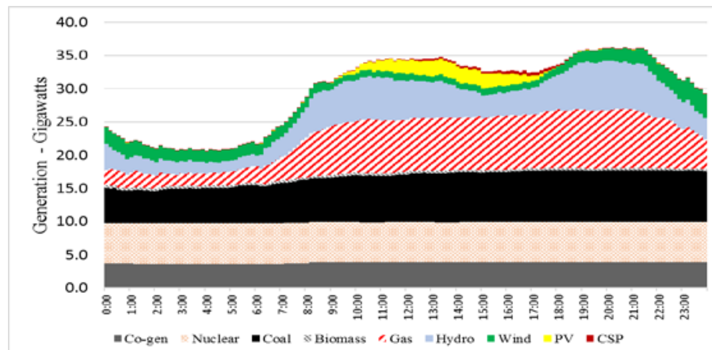

Figure 8 - Spanish Generation by Source - 8 January 2018 [25]

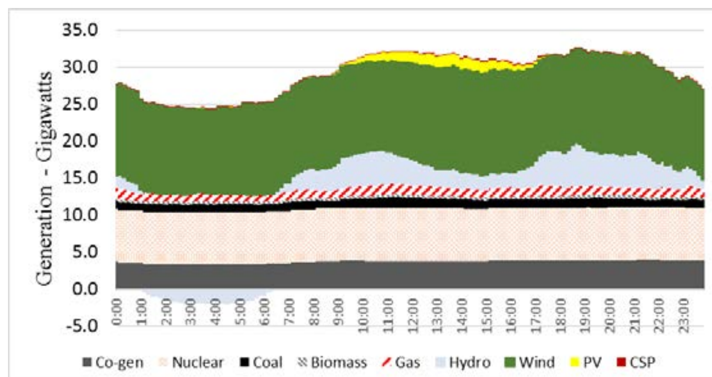

Figure 9 - Spanish Generation by Source - 4 January 2018 [25]

6.2. United Kingdom

The UK has over 18 GW wind plus 12 GW of solar capacity or 23% of the overall installed system capacity [21]. As shown in figures 10 and 11, during the observation period of 1-10 January 2018, the output from the UK's wind and solar resources varied from 6 % of the load on 10 January 2018 to 24% of the load on 3 January 2018. For the last year, about 14% of the overall need was supplied by wind and solar generation [26].

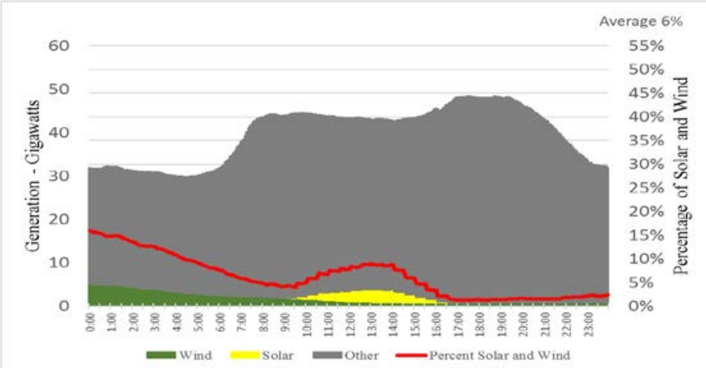

Figure 10 - UK Renewable Generation - 10 January 2018 [26]

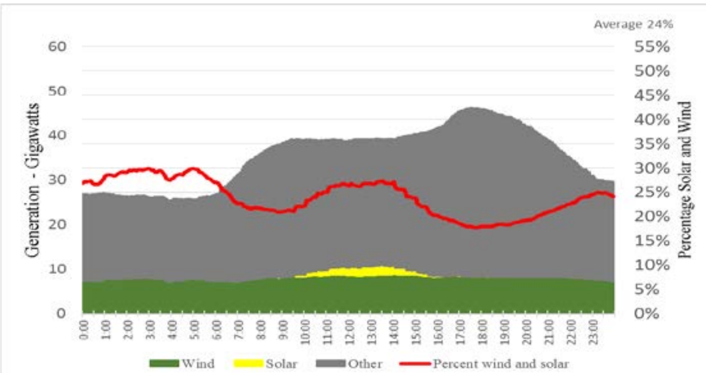

Figure 11 - UK Renewable Generation - 3 January 2018 [26]

6.3. Texas

Texas, with 24% of the installed capacity as wind, has the third highest exposure to renewables of the studied systems. The installed wind capacity is over 24 GW and expected to grow to 28 GW in the next three years [7]. Over the last year, it averaged 7 GW equivalent of supply or 13% of the total generation for the year. As shown in figures 12 and 13, in the observation period of 1 to 10 January 2018, the generation varied from about 5% of the need on 2 January 2018, an extremely cold day with a large load for the system, up to 39% on 10 January 2018. Nearly 42 GW of dispatchable power providing over 900 GWh of dispatchable energy was required to cover the load on 2 January 2018. By 10 January 2018, the use of dispatchable power was down to 7 GW and 170 GWh of energy (data [27][28]).

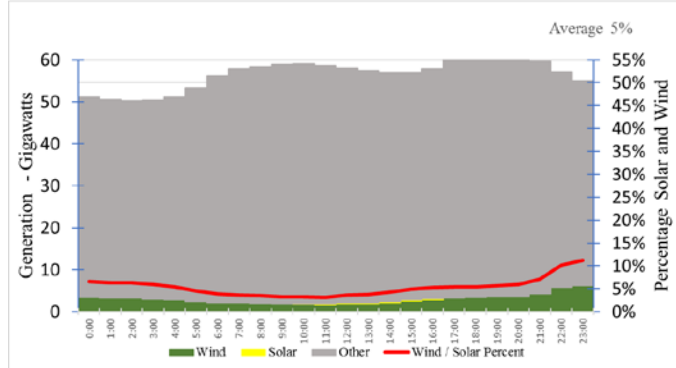

Figure 12 - Texas Renewable Generation - 2 January 2018 [27][28]

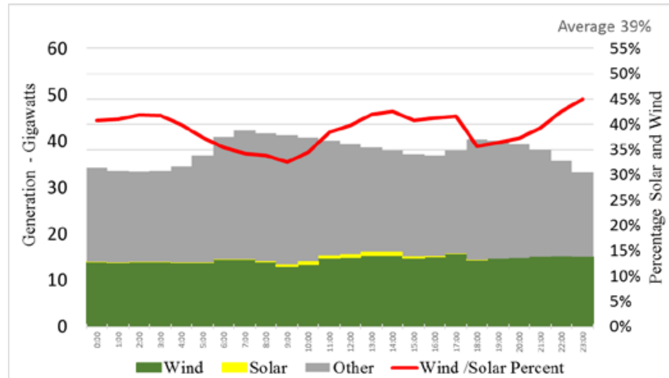

Figure 13 - Texas Renewable Generation - 10 January 2018 [28][27]

7. **Conclusions and Relevance for South Africa**

1. Internationally, there are a number of grid systems, similar in size to that of South Africa, that operate independently of larger network systems.
2. A number of these grid systems incorporate significant portions of wind and solar generation into the system and are able to maintain grid stability.
3. Dispatchable power is a requirement for the operation of the grid, with the amount of dispatchable power equaling or exceeding the amount of variable input from wind and solar.
4. In all of the grid systems reviewed, a significant portion of the dispatchable generation capacity comes from natural gas.

Currently, the South African electric grid is a very rigid system with the majority of the generation from baseload sources, with dispatchable power of 15% of the installed capacity, as seen in figure 14 [11][29]. This rigidity makes it quite challenging to increase the percentage of renewable generation in the system. The examples of other large independent systems and international studies indicate the need for dispatchable power availability to provide for the variability of renewables sources.

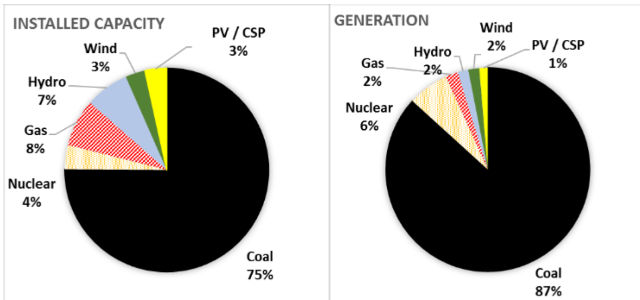

Figure 14 - South Africa Installed Capacity and Generation [11][29]

The plan for implementation of a revised generation system in South Africa to meet the greenhouse gas reduction target was laid out in the Integrated Development Plan of 2010 (IRP). In this plan, the government indicated the intent to develop 18.8 GW of renewable energy generation capacity by 2030, 8.4 GW of PV, 1.2 GW of CSP and 9.2 GW of wind. Associated with this renewable capacity, the plan indicated installation of 9.7 GW of dispatchable gas generation capacity, 2.4 GW of combined cycle and 7.3 GW of open cycle [30]. From the review of other large island systems, this seems to be a conservative target for renewable generation, but also one without sufficient allowance for dispatchable power.

The IRP development plan envisaged the installation of 9.6 GW of nuclear generation within the planning period. As can be seen from the large island systems reviewed, nuclear power is one of the firmest of base load generation. Thus, adding this large amount of base load generation would cause the already stiff system to become even stiffer. Even without renewable energy expansion, the emphasis should be on implementation of flexible, dispatchable power. For implementation of significant amounts of renewable solar and wind power, this additional dispatchable power is a necessity.

In the 2016 update to the IRP, the plan time horizon has been extended to 2050 and the base case target for renewables was increased to 55 GW, 17.6 GW of PV and 37.4 GW of wind [31]. This is quite consistent with the existing and planned installed capacity of renewables in the other large island systems. Along with this renewable generation, the plan calls for 35.3 GW of dispatchable gas, 13.3 GW of open cycle and 22 GW of combined cycle [31].

These plans envisage a significant buildout of the dispatchable gas generation capacity over the existing 5 GW of dispatchable gas, however, this may not be enough to facilitate the variability of the renewable generation. This would imply that there might be curtailment of the variable generation or other base generation would need to be used in mid-merit or peaking service, which is not where it is ideal.

The review of the international large island systems shows the need to have sufficient dispatchable power to allow the operation of the grid with significant variable generation, thus the development of this must be considered as an integral part of the development of the renewable based power system for South Africa.

Solar power generation can provide a significant portion of the power generation in South Africa. This, and other renewable energy sources, will be necessary for the country to achieve its stated greenhouse gas reduction goals. However, the installation of dispatchable generation is an essential complement in the implementation of renewable solar power development.

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