Guiding Principles for Grid Code Compliance of Large Utility Scale Renewable Power Plant Intergration onto South Africa's Transmission/Distribution Networks

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***Abstract*—Renewable energy generation technologies with its short lead times have become an attractive alternative to assist South Africa to solve its energy crisis and hence led to the Government calling upon Independent Power Producer to enter the market. Subsequently, the Integrated Resource Plan 2010 set a target of 17 800 MW (equivalent to 42%) of new electricity generation capacity in the country to be derived from renewable energy sources. The South African Renewable Energy Grid Code was then published in 2010 to assist with safe and technical integration of these plants into the South African grid. Electricity utilities are now faced with the task to understand the code and carry out testing of these renewable power plants in order to certify them grid code compliant. This paper assists by discussing the requirements of the South African Renewable Energy Grid Code Version 2.8 with testing methods to check grid code compliance.**

Keywords— Distributed generation; independent power producers; renewable energy independent power producer procurement programme; renewable power plants, South African renewable energy grid code

I. INTRODUCTION

The last century has demonstrated that every facet of human development is woven around a sound and stable energy supply regime[1]. South Africa (SA) with an estimated population of 53 million people, surface area of 1219912 square kilometers, a GDP of US$384.31 billion [2], is the 25th largest country in the world by land area, and the 24th-most populous nation. South Africa is ranked as an upper-middle income economy by the World Bank, and is considered to be a newly industrialized country. Its economy is the second largest in Africa, and the 28th largest in the world [3]. South Africa is currently facing its worst electricity supply side crisis in 40 years. Regular load shedding has been taking place since 2008 and is now predicted to last until 2018.

The construction of two new coal-fired power plants, Medupi and Kusile, of approximately 4800 MW each is severely behind schedule and subject to significant cost overruns. For the reasons of energy security, economic and environmental benefits, there has been increased interest in the usage of Independent Power Producers (IPP) renewable energy generation worldwide [4]. Even within South Africa there has been an increasing number of requests to connect Renewable Power Plants (RPP) onto Eskom and local municipal networks driven by energy shortages, load shedding, rising electricity tariffs, reducing costs of renewable energy technology, proposed carbon taxes, reducing carbon emissions for green marketing purposes, the Department of Energy (DOE) Renewable Energy Independent Power Producer Procurement Programme (REIPPPP), Distributed Generation (DG) ability to alleviate network congestion and to improve overall electricity security in South Africa [5].

The monopoly utility Eskom, which to date has generated 90 percent of the country's coal-fired electricity, is strapped for cash, ridden by crisis and has been struggling to build additional generation capacity required by the Integrated Resource Plan (IRP). By January 2015, one third of Eskom's installed capacity, approximately 15 000 MW was down and the country's reserve margin depleted. Electricity tariffs have tripled in real terms since 2005 and increased by a further 12.8 percent in April 2015. Eskom has been relying heavily on expensive diesel peaking plants to make up the shortfall but has long exhausted its budget for the 2015 financial year [6].

National debates continue over which options to solve the crisis are the quickest to construct, the most affordable and the most technically feasible. There are also pressures to meet national commitments to climate change mitigation pledged in 2009. In February 2015, the State President promised to do 'everything we can', including developing a 9600 MW nuclear fleet; constructing yet more coal-fired power plants; importing hydro from the Democratic Republic of Congo; importing gas from neighboring countries; developing the country's shale gas reserves; and undertaking demand-side management measures such as solar hot water heaters and rooftop solar PV. Decision-making over the ideal electricity mix reflects deeper struggles over what gets supported by the state, who gets to build it, and who gets to benefit. In the last three years, however, carbon-intensive, coal-dependent South Africa has become one of the leading destinations for renewable energy (RE) investment. The REIPPPP programme has successfully created an enabling framework for attracting substantial private sector expertise

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and investment for utility scale RE. It has delivered cost effective, clean energy infrastructure to the country and contributed to the security of electricity supply that is expected to bring about a virtuous circle of investment and economic growth. In a period of just less than five years, the country is proud to have secured significant investments in RE technologies. [6]

To date, South Africa's renewable energy policy of 2003 has largely been driven by a 10000 GWh target set by 2013 and renewable energy project subsidies offered through the Renewable Energy Finance and Subsidy Office (REFSO). From 2009 to 2011, a Renewable Energy Feed-In Tariff (REFIT) was considered and published, which resulted in great interest by IPP to develop renewable energy projects in South Africa. However due to legislative constraint in 2011, a competitive procurement entitled the REIPPPP was launched by the DOE in its place [7].

In terms of Section 34 of the South African Electricity Regulation Act (Act No. 4 of 2006), the Minister has determined that 3725 Megawatts (MW) to be generated from renewable energy sources is required to ensure the continued uninterrupted supply of electricity. This 3725 MW is broadly in accordance with the capacity allocated to RE generation in the IRP 2010 – 2030. This IRP procurement program has been designed to contribute towards the target of 3725 MW and towards social-economic and environmentally sustainable growth. On the 19th December 2012, the Minister of Energy made a new determination for the procurement of an additional 3200 MW capacity to the previous Determination of 3750 MW. The total capacity to be procured is currently 6925 MW [7].

While REIPPPP includes allocations for a range of technologies, the majority of capacity allocated is for wind, solar PV and solar CSP outlined in Table 1. The process was launched in the same year as the country's IRP 2010, an electricity master plan covering total generation requirements from 2010 to 2030. Under revision since 2013, IRP 2010 plans to double national capacity from approximately 41 000 MW to 89 532 MW by 2030. While coal is still set to dominate the generation mix, IRP (2010) seeks to increase the overall contribution of new renewable energy generation to 17 800 MW by 2030 (42% of all new-build generation). This will be generated by projects approved under REIPPPP and other private and state-managed projects. Winners of rounds 1, 2 and 3 were announced in December 2011, May 2012 and November 2013 respectively. Projects range in size from 20 MW to 139 MW for wind; 5 MW to 86 MW for solar PV; and 50 MW to 100 MW for solar CSP. The rounds 1 to 3 collectively represent a combined foreign and domestic investment commitments of approximately $14 billion/ R168 million. [6]

In round one of the programme, 28 successful bidders were selected making up a total of 1416 MW of capacity from these 28 projects. In round two, 19 projects were selected making up a capacity of 1045 MW. Whilst in round 3, 17 projects were selected making up a capacity of 1486 MW and in round 3.5 two projects of 200 MW capacity was selected. Round 4 consisted of 26 projects with a capacity of 2206 MW. Wind (3347 MW) and Solar PV (2327 MW) makes up the largest portion of the projects (6330 MW) selected under round 1 to round 4 of the DOE REIPPPP.

There has been a drastic reduction in the cost per kWh of wind and solar from round 1 to round 3. Table 2 depicts the average bid price for each technology in the REIPPPP round 1 to round 3.

Table 1 Selected bidders in the REIPPPP: Round 1 to 4 [6]

Technology	MW Awarded Round 1	MW Awarded Round 2	MW Awarded Round 3-3.5	Total MW's Awarded round 4	Total MW's Awarded Round 1 - 4
Solar PV	632	417	465	813	2327
Wind	634	563	787	1363	3347
Solar CSP	150	50	400	0	600
Landfill Gas	0	0	18	0	18
Biomass	0	0	16	25	41
Small hydro	0	15	0	0	15
Total	1416	1045	1686	2206	6330

Table 2 Average bid prices for REIPPPP round 1 to 3 [6]

Tariffs	Round 1 Average Bid (Per kWh)	Round 2 Average Bid (Per kWh)	Round 3 Average Bid (Per kWh)
Wind	R1.14	R0.90	R0.66
Solar PV	R2.76	R1.65	R0.88
CSP	R2.69	R2.51	R1.46

Figure 1 shows the locations of the DOE REIPPPP in the difference provinces in South Africa. The largest concentration of installed capacity of these projects are in the Northern Cape Province (2229.7 MW) and Eastern Cape Province (1072.6 MW). This is due to the good solar resources in the Northern Cape and good wind resources in the Eastern Cape.

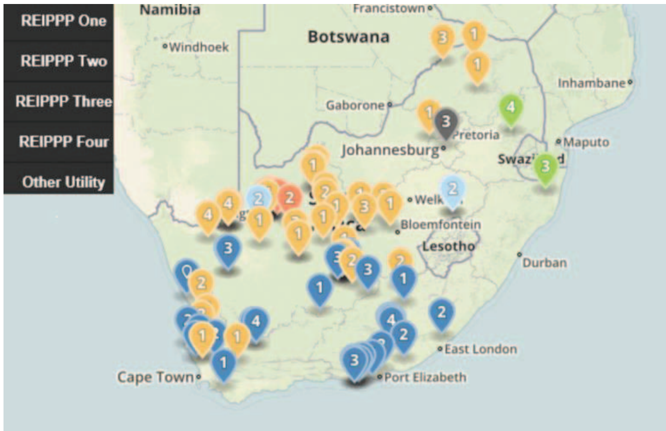

Fig 1 DOE RE round 1, 2, 3 and 3.5 preferred bidder's location in South Africa [7]

Since the launch of the REIPPPP, investment has gone from a few hundred million dollars in 2011 to \$5.7 billion in 2012, of which approximately \$1.5 billion was for wind and \$4.2 billion for solar, and \$4.8 billion in 2013, of which \$1.9 billion was for wind and \$3 billion for solar. This investment can largely be attributed to the unprecedented take off of the country's REIPPPP. Since then a privately-generated, utility scale, renewable energy sector has been integrated into an electricity network that has historically been dependent on the country's abundant coal resources and dominated by Eskom. The programme has now completed four bidding rounds and a separate round for concentrated solar power (CSP) only (round 3.5): 92 projects have been approved with a capacity of 6330 MW. REIPPPP is the first renewable electricity initiative to have gained traction at the national level in South Africa. Despite a significant delay in the introduction of this programme since its inception in 2007 as a feed-in tariff, it has been hailed as an unprecedented success. The RE country attractiveness index of EY (previously Ernest and Young) rated South Africa the 15th most attractive destination for RE investment. [6]

II. SA RENEWABLE ENERGY CODE

The South African Renewable Energy Grid Code (SAREGC) was created in 2010 and provide mandatory minimum guidelines for RPPs to connect onto the transmission and distribution networks in South Africa. The code was developed to help the country deal with the influx for IPP generation sources and to ensure that the grid stability and quality of supply standards were maintained. Table 3 shows the different RPP categories in accordance with the SAREGC. Plants are classified according to their size and connection voltage level.

The SAREGC provides minimum technical requirements that any RPP needs to comply with prior to the Network Service Provider (NSP) allowing commercial operation onto their grid. However many utilities are not familiar with the SAREGC requirements or how to go about carrying out grid code compliance testing of these RPPs. For the purpose of this paper, the focus will be on the requirements for the connection of large utility scale (Category C) MV/HV connected RPPs. It must be further noted that the SAREGC requires all testing of RPP compliance to the code to be done at the Point of Connection (POC) and not at the generator terminals as required by certain international codes.

Table 3 SA Renewable Energy Grid Code Categories [8]

Category	Minimum Size (kVA)	Maximum Size (kVA)	Connection Voltage
A1	0	13.8	LV connected
A2	13.8	100	LV connected
A3	100	1000	LV connected
B	0	20000	MV connected
C	>20000		MV/HV connected

III. SAREGC RPP PLANT DESIGN REQUIREMENTS

The SAREGC has many design and operation requirements from Category C RPPs which will be discussed in brief detail below with some practical testing methods to determine compliance which can be utilised by utilities to certify compliance to the Grid Code.

A. Tolerance to Voltage Deviations

The SAREGC requires Category C RPPs to be designed in order to operate continuously within the POC voltage range specified by U_{Min} and U_{Max} in Table 4.

Table 4 RPP continuous operating voltage limits [8]

Norminal (Un) [kV]	Umin (PU)	Umax (PU)
132	0.90	1.0985
88	0.90	1.0985
66	0.90	1.0985
44	0.90	1.08
33	0.90	1.08
22	0.90	1.08
11	0.90	1.08

B. Voltage Ride Through Capability

The capability of an RPP to be able to ride through voltage disturbances often caused by faults on the network is very important on the local network to ensure that stability of the grid is maintained at all times. Voltage-Ride-Through-Capability (VRTC) assists with preventing loss of generation on the network when a network voltage disturbance is experienced. Hence the code requires the RPP to be designed to withstand voltage drops to zero measured at the POC for a minimum period of 0.15 seconds. Category C RPP plants are also required to withstand voltage peaks up to 120% measured at the POC for a minimum period of 2 seconds. The required voltage operating capability of the RPP is shown in Figure 2 whilst Figure 3 shows the reactive power requirements from the RPP based on a function of the voltage.

VRTC, both Low Voltage Ride Through (LVRT) and High Voltage Ride Through (HVRT) is tested via a power systems simulation package such as Power Factory to simulate the appropriate low and high voltage durations and scenarios to ensure that the plant remains connected to the grid in the event of a disturbance on the network.

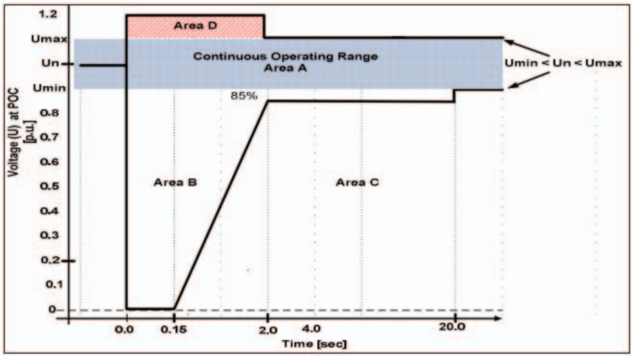

Fig. 2 VRTC for Category C RPP [8]

To check compliance, the IPP is required to provide the NSP with a type tested, manufacturer specific RMS model of their plant which can then be used to check how the plant behaves for different under and over voltage conditions on the network. Checks need to be done to ensure that no disconnection of the plant occurs as long as the POC voltage remains within the lower and upper limit curve (area A, B and D) in Figure 2.

The SAREGC requires the RPP to either supply or absorb reactive current based on the function of the POC voltage (LVRT or HVRT) level following a network incident. It looks at two cases, a case of over voltage and a case of under voltage at the POC. Figure 3 shows the Area A which is the normal operating area (0.9 ≤V≤ 1.1), Area B (0.9 <V≤ 0.2), and Area E (V<0.2), where reactive current support is required to help in stabilizing the voltage whilst Area D (V>1.1) requires reactive current absorption to assist in reducing the voltage. [7]

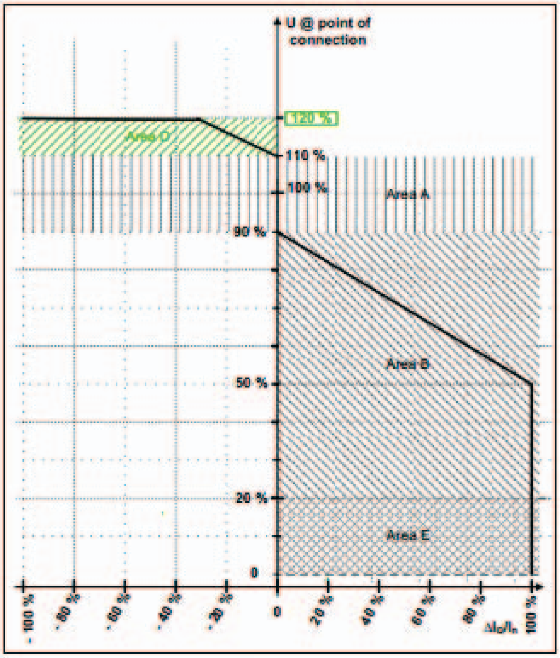

Fig. 3 Reactive power requirements during voltage drops or peaks from Category C RPP [8]

LVRT studies need to be carried out for the 7 case studies defined in Table 5 and three scenarios for each case study defined in Table 6.

Table 5 Case Studies to be carried out for LVRT studies

Study Case	Number of Affected Phases	Fault Duration	Retained Voltage U_{rt} [PU]
1	1	0.15	0.00
2	2	0.15	0.00
3	3	0.15	0.00
4	3	0.59	0.20
5	3	1.24	0.50
6	3	1.67	0.70
7	3	20.0	0.85

Table 6 Scenario's for initial network parameters for LVRT

Scenario	Active Power P	Reactive Power Q	Voltage at POC
a	P = Pn	Q = QMax	U = Un
b	P = Pn	Q = 0	U = UMax
c	P = Pn	Q = QMin	U = UMax

Figure 4 shows an example of a LVRT study carried out for a three phase fault with a zero retained voltage for 150 milliseconds. Figure 4 shows the RPP reduces its active power and increases its reactive power during the fault as the voltage drops to zero and remain connected for the 150 millisecond duration as required by the SAREGC.

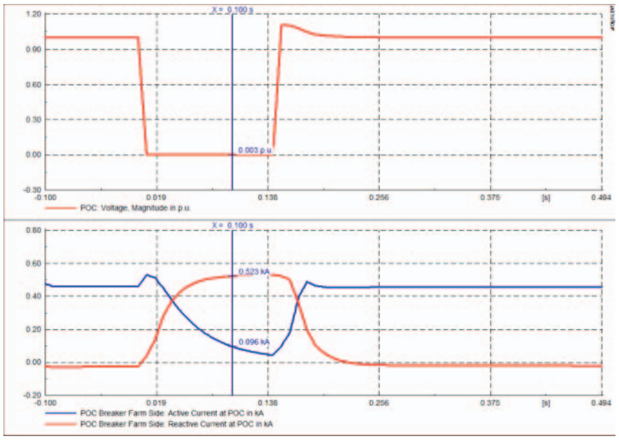

Fig 4 Example of a LVRT Test for a three phase fault with zero retained voltage for 150 milliseconds

C. Tolerance to Frequency Deviations

The RPP is required to be designed to operate continuously from 49 – 51 Hz and the plant must be able to withstand phase jumps of up to 20°. However if the frequency exceed 52 Hz for greater than 4 seconds or less than 47 Hz for greater than 200 milliseconds then the plant is allowed to disconnect from the network as depicted in Figure 5. This simulates an over frequency and under frequency event on the grid. [7]

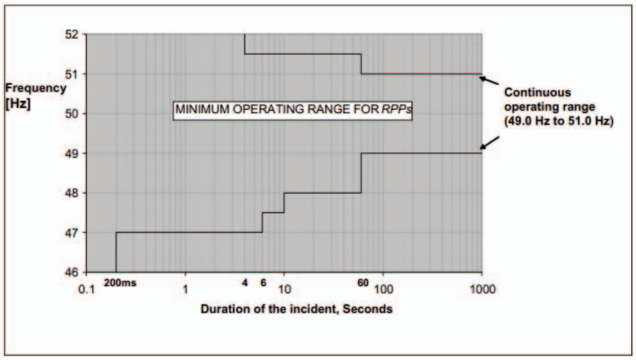

Fig. 5 Minimum RPP plant frequency operating range [8]

D. *Frequency Response Requirements*

Frequency F2 to F3 forms a dead band where there is no requirements from the plant whilst F1 and F4 forms a Control Band. Once the frequency exceed F2, indicating an under frequency event (the load exceeds the network generation), the plant is required to injected P_{Delta} into the network to assist in stabilizing the frequency. The plant is required to follow the Droop 1 setting on the network. Where Droop is defined as a percentage of the frequency change required for an RPP to move from no-load to rated power or from rated power to no-load. All RPPs are required to be equipped with frequency controlled Droop settings which shall be adjustable between 0% and 10%. During an over frequency event, the network frequency will exceed F3 (there is more generation than load on the network), the plant is required to follow the Droop 2 setting. This dictates the reduction in power required from the RPP for a change (increase) in frequency. Figure 6 and Table 7 indicates the required default plant frequency settings.

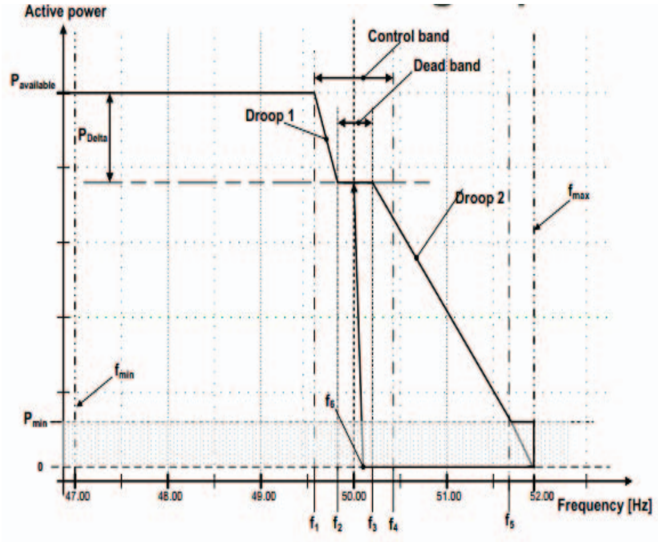

Fig. 6 Frequency response requirement for Category C plant [8]

Frequencies f_1, f_2 and f_3 shown in Figure 6 and Table 7 will be set and agreed by the IPP and the SO.

Table 7 Required frequency default settings [8]

Parameter	Magnitude
f_{min}	47
f_1	As agreed with the SO
f_2	As agreed with the SO
f_3	As agreed with the SO
f_4	50.5
f_5	51.5
F_6	50.2
f_{max}	52

To prove grid code compliance to the frequency response curve in Figure 6, a frequency generator is required to inject the frequencies shown in Table 7. This is done to simulate an under frequency event on the grid to check if the RPP behaves according to the requirements of Figure 6 in an under frequency situation. At the start of the test, select a value for P_{Delta} (P_{Delta} shall be minimum 3% of $P_{Available}$) which is a percentage of $P_{Available}$ and a suitable Droop 1 and Droop 2 (value range from 0 to 10% although Droop 1 is usually selected at 4% and Droop 2 at 8% for testing purposes). Calculation of the Droop settings are shown in Figure 7. To test the frequency of the RPP, carry out the 5 tests depicted in Table 8 and record the results. Compliance of the tests is determined if the recorded results after 10 seconds is within ±2% of the set point value or ±5% of the rated power, depending on which yields the highest tolerance. [7]

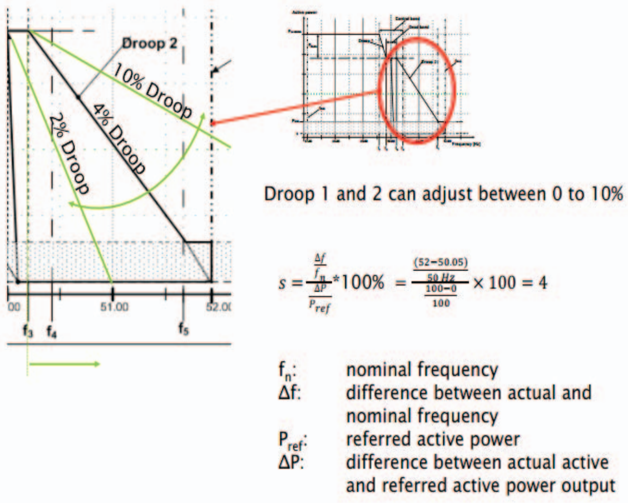

Fig. 7 Calculation of the Droop [9]

Table 8 Test for Under Frequency response [10]

Set value of P_{Delta}:	Eg. _10__% of $P_{Available}$
Set value of Droop 1:	4%
Test Set Point 0	50.00 Hz
Test Set Point 1	49.85 Hz
Test Set Point 2	49.50 Hz
Test Set Point 3	49.00 Hz
Test Set Point 4	48.00 Hz
Test Set Point 5	50.00 Hz

To simulate an over frequency event on the grid to check if the RPP behaves according to the requirements of Figure 6 in an over frequency situation. Select a suitable Droop 2 and use a frequency generator to simulate the frequencies in Table 7. Carry out the 6 tests depicted in Table 9 and record the results to ensure that the RPP respond within the required time and accuracy to check compliance.

Table 9 Test for Over Frequency response [10]

Set value of Droop 2:	8 %
Test Set Point 0	50.00 Hz
Test Set Point 1	50.50 Hz
Test Set Point 2	51.00 Hz
Test Set Point 3	51.10 Hz
Test Set Point 4	51.20 Hz
Test Set Point 5	51.50 Hz
Test Set Point 6	52 Hz

IV. CONTROL FUNCTIONS REQUIRED FOR RPP

The RPP is required to have the following control functions as shown in Table 10.

Table 10 Control functions required from RPPs [8]

Control Function	**Category C**
Frequency Control	x
Absolute Production Constraint	x
Delta Production Constraint	x
Power Gradient Constraint	x
Reactive Power (Q) Control	x
Power Factor Control	x
Voltage Control	x

A. *Reactive Power Capability*

The grid code specify the reactive power requirements from Category C plant [$-0.33 \leq (Q/P_{Max}) \leq 0.33$] measured at the POC. The grid code requirements are shown in Figure 8.

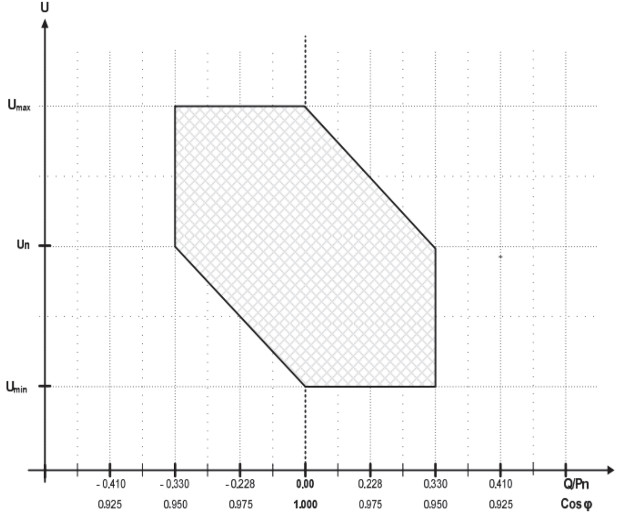

Fig. 8 Reactive power requirements [8]

To check grid code compliance of RPPs with regards to reactive power requirements, tests and measurements shall be carried out in accordance to the Table 11 and Figure 9 which is for the case of U = 1 PU. If U is equal to U_{Max} then test set point 3, 4 and 5. If U = U_{Min} then test set point 1, 2 and 3 only. The measured values shall be recorded after 30 seconds after receipt of the set point to a measured accuracy to the higher value of either ±2% of the set-point value or ±5% of maximum reactive power.

Table 11 Reactive Power Q Control Test at $P_{Available}$ [10]

Reactive Power (Q) Control Test	
Test 1	P = 20% P_{Max}
Set Point 1	Q = 0 Mvar
Set Point 2	Q_{max}=0.33 P_{Max} (overexcited)
Set Point 3	Q = 0 Mvar
Set Point 4	Q_{max}=-0.33 P_{Max} (underexcited)
Set Point 5	Q = 0 Mvar
Test 2	Carry out Test 1 with P = $P_{Available}$

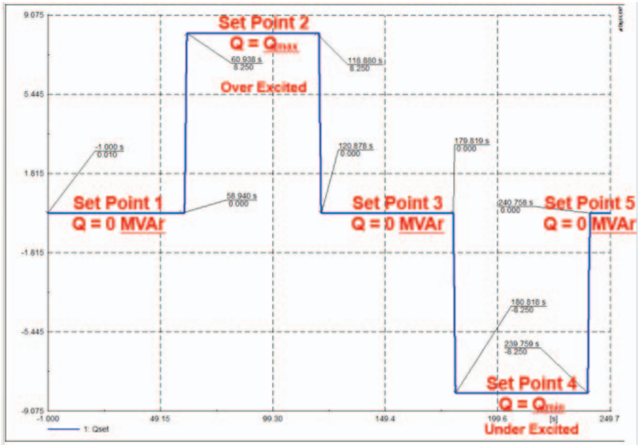

Fig 9 Reactive Power Capability Test set points at U = 1

B. *Power Factor Control Function*

Category C: RPP shall be designed to operate from 0.95 lagging to 0.95 leading Power Factor, measured at the POC from 20% and above of the rated power.

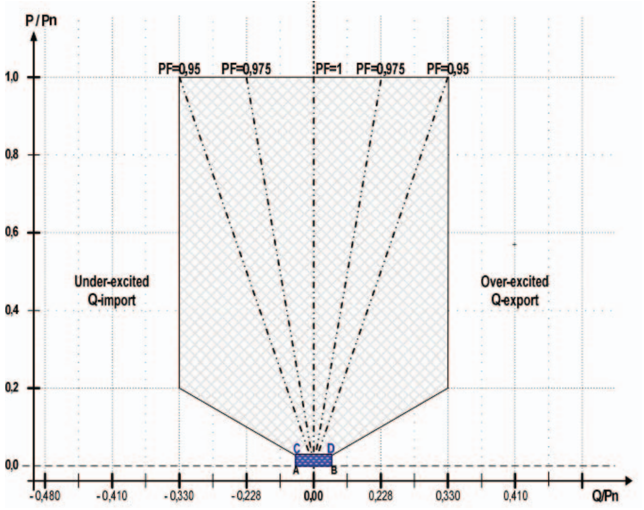

Fig. 10 Power Factor requirements from RPP [8]

The RPP is required to respond within 30 seconds of receipt of the set point to a measured accuracy of ±0.02 in order to pass the test. The test that needs to be carried out is shown in Table 12 and Figure 11 which tests the RPPs ability to meet the required Power Factor values in Figure 10. The plant must be able to operate at the required Power Factor from P ≥20% P_{Max}.

Table 12 Power Factor Control function test [10]

Reactive Power Control – Fixed Cos (φ)	
Test Set Point 1	PF= 1
Test Set Point 2	0.95 overexcited
Test Set Point 3	PF= 1
Test Set Point 4	-0.95 under excited
Test Set Point 5	PF= 1

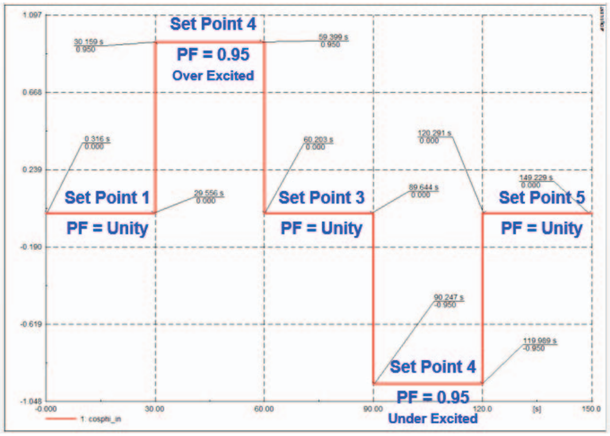

Fig. 11 Simulation of Power Factor test set points for RPPs

C. *Voltage Control Functions*

The voltage control function for RPPs is depicted in Figure 12. If the RPP voltage set point is to be changed, a set point is issued and the change needs to be implemented within 30 seconds with the accuracy of ±0.5% of $V_{Norminal}$ whilst the accuracy of ±2% of the required injection or absorption of reactive power according to the defined Droop characteristic. The tests to be carried out are depicted in Table 13, Table 14, Figure 13 and Figure 14 using 4% and 8% Voltage Droop.

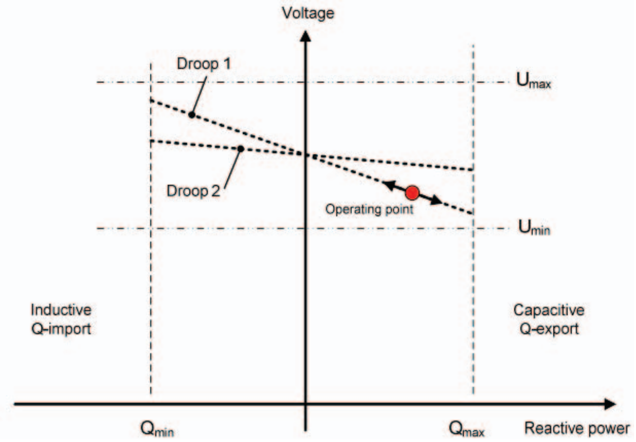

Fig. 12 Voltage Control for RPPs [8]

Table 13 Voltage Control Function Test with 4% Voltage Droop [10]

Reactive Power Control – Q(U) characteristic	
Test 1	Set the Droop to 4%: (Q_{max})/4% U_n
Set Point 1	Nominal Voltage
Set Point 2	1.02 of Un
Set point 3	Nominal Voltage
Set Point 4	0.98 of Un
Set Point 5	Nominal Voltage

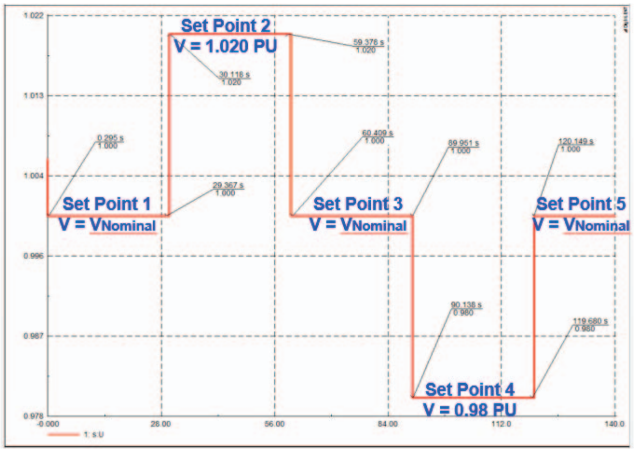

Fig. 13 Simulated Voltage Control Test set points with 4% Voltage Droop

Table 14 Voltage Control Function Test with 8% Voltage Droop [10]

Reactive power control – Q(U) characteristic	
Test 2:	Set the Droop to 8%: (Q_{max})/8% U_n
Set Point 1	Nominal Voltage
Set Point 2	1.04 of Un
Set Point 3	Nominal Voltage
Set Point 4	0.96 of Un
Set Point 5	Nominal Voltage

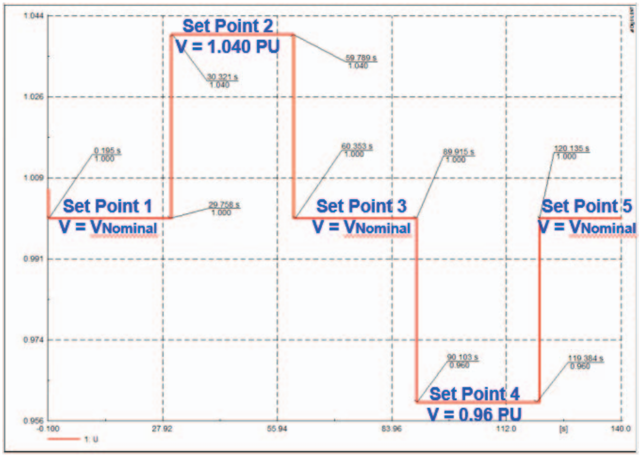

Fig.14 Simulated Voltage Control Test set points with 8% Voltage Droop

A. Power Quality

Power Quality is required to be monitored at the POC and the following parameters shall be monitored:

[1] Rapid voltage change
[2] Flicker
[3] Harmonics
[4] Unbalance voltage and current

These Power Quality (PQ) parameters can be checked utilizing the type tested, manufacturer specific model in a Power Systems simulation package prior to the construction of the RPP. Post construction of the RPP, on site PQ meters can be installed to gather the data which can then be utilized to check compliance against values given to the IPP by the NSP. The PQ limits given by the NSP to the IPP are apportioned values which takes the PQ limits given in South African National Rationalisation Standard 048 and apportioned to the upstream contribution together with current and future customers' contribution limits. If the plants violates the PQ limits, then the IPP will need to design filters to be installed to ensure compliance.

B. Active Power Constraint Function

For reasons of system security, the RPP may be requested to curtail active power output when requested by the SO. Hence the RPP shall have the following active power constraint functions shown in Figure 15.

[1] Absolute Production constraint
[2] Delta Production constraint
[3] Power Gradient constraint

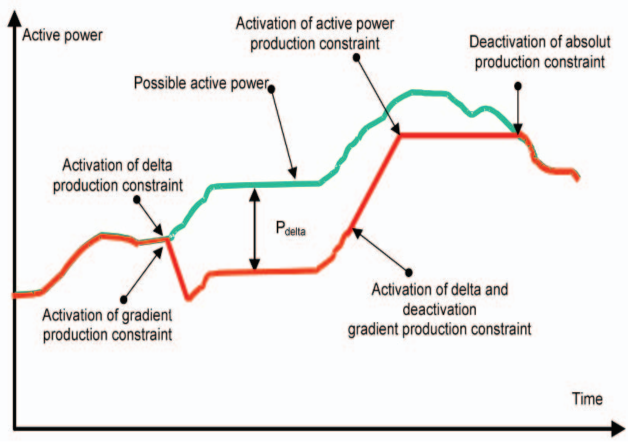

Fig. 15 Required RPP active Power Control Functions [8]

C. Absolute Power Constraint Function

An Absolute Production Constraint (APC) is used to constrain the output active power from the RPP to a predefined power MW limit at the POC. This is typically used to protect the network against overloading. In order to check compliance of the RPP to the APC function, the plant shall be tested as per Table 15. The measured values shall be recorded after 30 seconds after receipt of the set point to a measured accuracy to the higher value of either ±2% of the set point value or ±5% of the rated power for each set point. If the plant meets the required set point within the time period and accuracy limit, then the plant passes this test. [7]

Table 15 Tests to check operation of Absolute Power Constraint function [8]

Testing of the Absolute Power Constraint Function	
Select a $P_{reference}$ value in MW	
	Decreasing Limit Test
Test 1	$P_{reference}$ to 80% $P_{reference}$
Test 2	80% $P_{reference}$ to 40% $P_{reference}$
Test 3	40% $P_{reference}$ to 20% $P_{reference}$
Test 4	20% $P_{reference}$ to 10% $P_{reference}$
	Increasing Limit Test
Test 5	Increasing limit to 30% $P_{reference}$
Test 6	30% $P_{reference}$ to 50% $P_{reference}$
Test 7	50% $P_{reference}$ to 80% $P_{reference}$
Test 8	80% $P_{reference}$ to 0% $P_{reference}$
After the 8th test the RPP shall go back to normal operation	

D. Delta Production Constraint Function

A Delta Production Constraint (DPC) function is used to constrain the active power from the RPP to a required constant value in proportion to the possible active power. It is typically used to establish a control reserve for control purposes in connection with frequency control. To check compliance of the RPP to the DPC function, the plant shall be tested as per Table 16. P_{Delta} must be selected as a percentage of $P_{Available}$ which shall be 1 MW or greater. Tests can be carried out only if $P_{Available}$ is greater than 20% P_{Max}. The measured values shall be recorded after 30 seconds after receipt of the set point to a measured accuracy to the higher value of either ±2% of the set point value or ±5% of the rated power for each set point. If the plant meets the required set point within the time period and accuracy limit, then the plant passes this test.

Table 16 Tests for of Delta Production Constraint function [10]

	Delta Production Constraint Function Test
	SETUP
1.	Check P_{Delta} control enabled
2.	Send ___e.g. 10% of $P_{Available}$ (> 1 MW)
3.	Check if power reduces to set point value on Power Park Controller, SCADA or better measurement system.
4.	Hold for at least 10 min
5.	Further tests as optional. For example longer period if the primary energy do not change during the 10 minute test period or other setting like P_{Delta} of 3% would be tested
6.	Disable P_{Delta} control

E. Power Gradient Constraint Function

A Power Gradient Constraint (PGC) Function is used to limit the RPP maximum ramp rates by which the active power can be changed in the event of changes in primary renewable energy supply or the set points for the RPP. A PGC function is typically used for reasons of system operation to prevent changes in active power from impacting the stability of the network. The test to check compliance is shown in Table 17. The measured values shall be recorded after 30 seconds after receipt of the set point to a measured accuracy of the higher value of either ±2% of the set point value or ±5% of the rated power for each set point. If the plant meets the required set point within the time period and accuracy limit, then the plant passes this test. [7]

Table 17 Tests to check operation of Power Gradient Constraint function [10]

Testing of the Power Gradient Constraint Function	
The active power has to set to $P_{reference}$ before the start of 1st test.	
	Down ramp rate has to be set to: (0.4 x $P_{reference}$)/min
Test 1	$P_{reference}$ to 20% $P_{reference}$
Pass Criteria	Plant needs to reach 20% $P_{reference}$ in 2 minutes
	Up ramp rate has to be set to : (0.4 x $P_{reference}$)/min
Pass Criteria	Plant needs to reach 20% $P_{reference}$ in 2 minutes
Test 2	20% $P_{reference}$ to $P_{reference}$
	Down ramp rate has to be set to : (0.2 x $P_{reference}$)/min
Test 3	$P_{reference}$ to 20% $P_{reference}$
Pass Criteria	Plant needs to reach 20% $P_{reference}$ in 4 minutes
	Up ramp rate has to be set to: (0.2 x $P_{reference}$)/min
Test 4	20% $P_{reference}$ to $P_{reference}$
Pass Criteria	Plant needs to reach $P_{reference}$ in 4 minutes
After the last test the RPP is allowed to go back to normal operation	

F. Signal, Communication and Control Requirements

Table 18 shows the signals that are required from the RPP plant. This will then assist the System Operator to manage the RPP connection together with the network more effectively. Each signal list is made up of a number of signals.

Table 18 Signal required from the RPP plant [8]

Signals List	Description
List 1	General plant data and set points
List 2	RPP available estimate
List 3	RPP MW curtailment data
List 4	Frequency response system settings
List 5	RPP Meteorological data

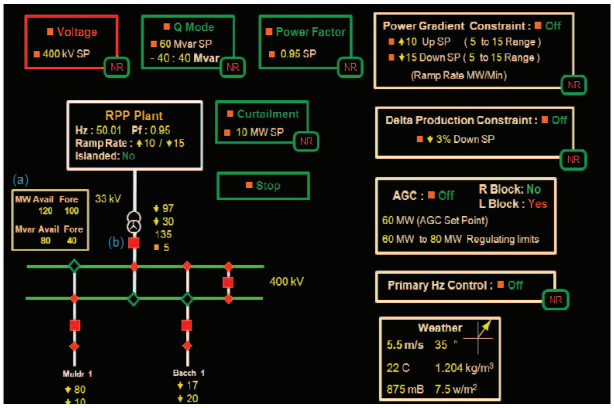

Fig 16 Example of signals brought back via SCADA [8]

Figure 16 shows a typical screen of signals brought back to the network control room via SCADA from an RPP.

G. Testing of SCADA Compliance

The following tests shall be performed from the Network Service Providers Control Room to the RPP Power Park Controller on the day of the grid code compliance tests.

[1] Check capability to remotely open the breaker at the POC from the respective NSP SCADA. Capability to change the mode of operation at the RPP.

[2] Check capability to change the set-point in any mode of operation such that the RPP adjusts accordingly.

[3] Anti-islanding Test: The facility shall be subjected to a self-islanding condition to determine the response of the ant-islanding protection function. Following this test, the RPPs automated response to the synchronisation function to the network at the POC shall be evaluated. [10]

V. CONCLUSION AND RECOMMENDATIONS

With the current electricity shortages and drive towards RE in South Africa which was once dominated by coal fired power stations, there are many opportunities been unlocked to drive the RE sector. To date, 92 projects were selected as part of the REIPPPP with a capacity in excess of 6330 MW. Compliance to the SAREGC is mandatory and all RPPs must comply with the code at the POC onto the utility grid in order to operate commercially. There are many renewable projects that are located all around the country with a challenge by many utilities and developers in understanding the complex requirements from the grid code and testing methods that can be employed to check grid code compliance. The SAREGC Version 2.8 is currently undergoing further changes to include more detailed protection requirements, power quality requirements and amendments to the requirements from synchronise generator technology RPPs. This paper provides a simple introduction to utilities and developers on the SAREGC requirements and provide some simple yet practical testing methods that can be employed to prove grid code compliance of RPPs.

With all RPPs complying with the Grid Code, it will make operating and managing the transmission and distribution network easier for the System Operator at the Eskom National Control room or at the NSP Control room. This will ensure that the System Operator will have both control and visibility of these RPP plants making it dispatchable and controllable. Currently, one unit (800 MW) of the Madupi Power Station has been commissioning and approximately 2000 MW of RPPs connected onto the National Grid in South Africa with a number of RPP projects still in design, implementation or commissioning stages. This has helped assist with the countries power shortage problems and drastically reduced the risk of load shedding.

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