8TH SOUTHERN AFRICA REGIONAL CONFERENCE

14 - 17 NOVEMBER 2017

"Electricity Supply to Africa and Developing Economies …. Challenges and opportunities."

Power System Resilience

Power system resilience – enablers supporting an effective Blackout response

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1. ABSTRACT

Electricity plays an essential role in the economy and in society in general. A major electricity-related incident can therefore have a significant impact on the country. Regulatory instruments require that a utility plan for a range of contingency scenarios, including those that have a high impact but a low probability of occurring.

This paper focuses on the resilience and technical planning required for a blackout event and discusses the different blackout recovery mechanisms available to the System Operator to respond to and recover from such an extreme contingency scenario within the South African context.

Furthermore the paper discusses the blackout recovery phases and technical considerations for responding to a blackout incident. It provides a view on the blackout planning required by unpacking recovery mechanisms, response objectives and response principles in compiling a technical response plan. The paper concludes with a discussion on the blackout facilities and highlights the SA Grid Code (SAGC) and System Operator requirements for black-start capabilities, such as: (i) Islanding schemes, (ii) Nuclear safety, (iii) Black-start facilities and (iv) Independent Power Producers.

2. INTRODUCTION

Electricity is the backbone of any developing and industrialised economy [1], [2]. Therefore, regulator instruments would influence the operating and maintenance of the Integrated Power System (IPS) for normal and abnormal network configurations. In the event of a national blackout incident, the most likely cause is an unforeseen sequence of events which results in a cascading loss of generation (and/or the transmission system), eventually leading to a complete loss of supply across the country. Eskom[1] relies on the islanding capability of its generating units, failing which the black-start facilities will be deployed to

[1] Eskom is a vertically integrated, South African state-owned electricity company, established in 1923. The utility is the largest producer of electricity in Africa, and is among the top seven utilities in the world in terms of generation capacity and among the top nine in terms of sales. (www.eskom.co.za)

energise the power system. This is supported by the technical restoration planning required to ensure the success of the restoration of the integrated power system.

Although the power system has multiple defence barriers, these cannot guarantee with absolute certainly that a blackout will never occur. Such an event could develop with little to no warning. While the initial restoration of loads could take several hours, the entire restoration of the power system could take up to several days.

3. UTILITY OBLIGATION

The protection of critical infrastructure, such as that for electricity provision, is crucial to government, regulatory bodies and society in general. There is a high interdependency with other sectors and impacts on practically all economic activities, the wellbeing of society as well as the security of the nation. Therefore, it is incumbent on the utility to be prepared for an eventuality such as the entire disconnection of the IPS. Eskom's obligation as a regulated entity is directed by a number of legislative and regulatory instruments, such as the Electricity Act, SAGC, Disaster Management Act / Framework, etc. [3]–[6]. These instruments require the System Operator to plan and prepare for a range of disaster scenarios by compiling response and recovery plans as well as developing the capabilities to respond to extreme incidences including that of a national blackout [2], [7], [8].

3.1 DISASTER MANAGEMENT

Effective disaster management principles would require planning for disaster prevention, as well as developing the capability to effectively respond and recover from such a disaster. The National Disaster Management Framework (NDMF) is the legal instrument specified by the Disaster Management Act to address such needs for consistency across multiple interest groups.

Eskom's disaster planning for a national blackout incident needs to address the Key Performance Areas (KPAs) as defined in the NDMF, namely:

- KPA 1 - institutional arrangements
- KPA 2 - risk assessment
- KPA 3 - risk reduction
- KPA 4 - response and recovery

3.2 SOUTH AFRICAN GRID CODE

The SAGC defines the obligations and roles for a Transmission licensee for the operation, management and planning of an interconnected transmission power system. These codes serve as a guiding document for regulatory business obligations, especially the responsibility of the System Operator. Furthermore, it assigns duties for coordination of technical and regulatory requirements to minimise the risks to the IPS and to support the integrated response to incidents. The System Operator has therefore established various technical support areas to support the control centre so as to safeguard the integrity, security and safe operation of the IPS, with a focus on efforts to avoid a national blackout incident.

The System Operator obligations are defined as follows:

- ***Scheduling of generation and ancillary services*** *(incl. demand response, reserve margins, black-start, unit islanding capability, and testing of these facilities);*
- ***System reliability and safety*** *(incl. connection conditions, load curtailment, generation merit order, loadshedding protocols, emergency and contingency planning);*
- ***System security*** *(incl. frequency, voltage and power quality, and specialised protection systems);*
- ***Agreements for off-site supplies to nuclear power stations (****incl. ensuring operable grid connection);*
- ***Operational measures*** *(incl. protection schemes, procedures, outage coordination and fault management).*

4. BLACKOUT INCIDENT

A national blackout remains a low-likelihood high-consequence disaster scenario, given the various system defence barriers in place to prevent this [2]. Therefore, the most likely cause of a national blackout would be an unforeseen sequence of events that results in a cascading collapse of the transmission/generation system, leading to a complete loss of electricity supply across the country. In recent CIGRE studies of major disruptions of IPS, it was suggested that an event results from an initiating incident (e.g. labour unrest, etc.) and/or an onset led by rapid change in frequency and/or a decaying voltage [1], [9].

As stated previously in Section 3, a responsible utility should continually review its technical and non-technical vulnerabilities to prevent and recover from a national blackout incident. The planning for a national blackout incident aims at lessening the chances of the disaster occurring and enhancing the defence barriers established to reduce the likelihood and contain the incident. The prevention of and planning for such incidents, as well as the ability to effectively respond to, and recover from such incidents are essential for building the resilience of the power system [8].

4.1 DESCRIPTION OF BLACKOUT RECOVERY PHASES

The restoration of an IPS is described through multiple recovery phases, i.e. ***Reaction***, ***Response***, ***Restoration***, ***Reconfirm*** *and* ***Recovery***. The transition between recovery phases shall be declared by the National Control Centre considering the status and stability of the IPS. This is determined by the evaluation of the real-time IPS constraints (e.g. available generation, transmission system status, available customer load and coordination with regional control centres [i.e. distribution system], weak interconnected system, safe operating of equipment close to technical limits and the principle of ensuring the integrity of IPS to prevent the next blackout incident). This requires the continuous management of the IPS to ensure that there are means to respond to the next incident that may occur during the restoration.

These blackout recovery phases consider the power system status and organisational condition to contain, maintain and monitor the status of emerging risks and threats to the response plans and capabilities. NB: *The greater the level of deviation from resilience capabilities, the likely more difficult it will be to meet required response plans and capabilities, with the resultant impact of prolonging the duration of the recovery, and hence the overall blackout emergency*.

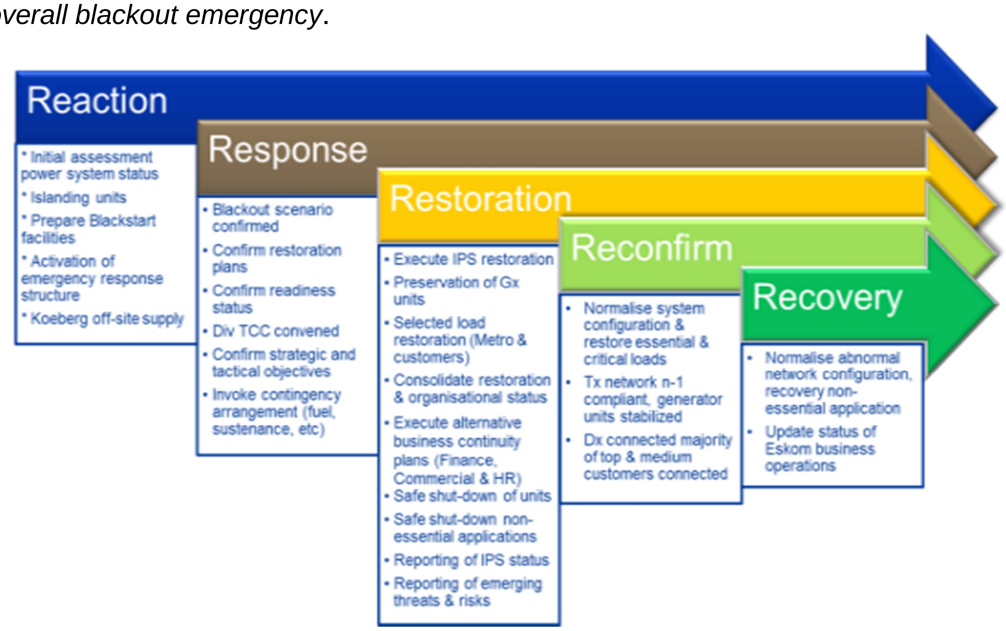

Figure 1: *Proposed National Blackout recovery phases*

Figure 1, illustrate proposed national blackout recovery phases is described as follows:

- **Reaction:** is typically known as the "initial attack" to respond to the incident to contain the consequence and preserve the plant. It requires the invoking of emergency response structures and system operating procedures to safeguard personnel, plant and the environment.

- **Response:** it requires the confirmation of the blackout scenario to determine the extent of the problem, the status of IPS and the projected restoration time. The invoking of contingency planning and response partners would enable a quicker restoration of a stable IPS. The organisational emergency response structures are convened and the blackout response objectives at different levels within the organisation are confirmed. It also requires the status confirmation of the disruption and/or safe shutdown of time critical processes/operations when a blackout occurs.

- **Restoration:** The initial phases of recovery allow the restoration of the IPS to commence only at operational level and a very limited organisational response has been invoked. Only at this stage would IPS operational restoration and strategic / tactical objectives be aligned. During the restoration phase, the preservation of generation units, reconnection of selected metros and major customers will be confirmed. A typical business condition would require an alternative organisational process which includes the safe shutdown of pre-defined business systems. Continuous reporting of emerging threats and risks could influence the safe operations of the IPS.

- **Reconfirm:** During the reconfirm phase the stability and integrity of IPS is confirmed to restore essential and critical loads. This is characterised by the establishment of the IPS in terms of typically n-1 criteria and stabilised generator units. It will allow distributors to connect large and medium customers to stronger network.

- **Recovery:** As the IPS is recovered, the less time-sensitive processes/operations are re-established to resume production/services. At this stage, the IPS will have been restored to the "original" state and normal operating and maintenance could commence. This may require repairs and restoring the primary site and conducting a post-mortem to extract lessons learnt.

5. PLANNING TO RESPOND TO A BLACKOUT

The ability of a utility to respond and recover in a coordinated manner to a national blackout incident depends on the resilience strategies adopted prior to it occurring [10]. It therefore requires that appropriate design, asset management and operational philosophies be adopted to contain the severity and quicker recover. This establishes the capabilities (e.g. black-start, unit islanding, standby generators, etc.) and abilities (e.g. technical response plan, etc.) necessitated by the obligation previously discussed. **Error! Reference source not found.**, illustrates the blackout bow-tie analysis technique adopted for the integrated risk assessment with the defense and recovery barrier mechanisms [11]. The following sections will focus the discussion on the blackout recovery mechanisms.

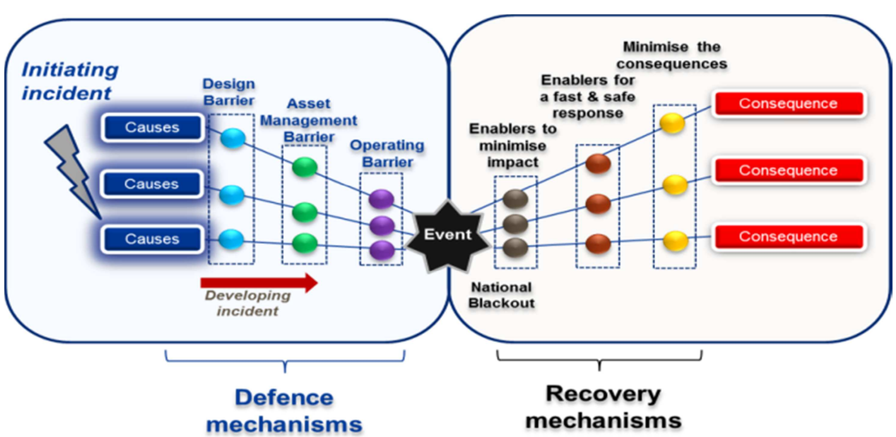

Figure 2: *Bow-tie risk visualisation for a blackout defence and recovery mechanisms*

5.1 BLACKOUT RECOVERY MECHANISMS

While the IPS has multiple defense barriers, these cannot guarantee that a blackout will be avoided [2], [8]. This is due to the potential limitations in the defense barriers. Thus, the restoration of loads and normalisation of the IPS would take several hours and weeks considering the initiating incident(s), plant/network failure(s) and ability for larger process customers to restore loads. It focuses on efforts that support the blackout restoration process to achieve the following: (i) create islands; (ii) stablise islands and (iii) synchronise islands.

The blackout recovery objectives will focus on minimising the severity; maximising the safety and restore by not comprising the integrity of the restoration. Therefore, recovery phases should evaluate the IPS status and organisational condition to contain, maintain and monitor the emerging risks and threats to the response and contingency plans.

The blackout recovery barriers have controls which would be influenced by escalation factors that modify the control's effectiveness. The goals during the initial reaction, response, restoration, reconfirmation and recovery of the IPS are:

- *Enablers to minimise impact;*
- *Enablers for a fast and safe response; and*
- *Efforts to minimise the consequence.*

5.2 BLACKOUT RESPONSE OBJECTIVES

In terms of the Incident Command System (ICS) the blackout response objectives to a blackout are defined for the emergency response structures at the strategic, tactical and operational levels. These objectives establish the foundation for coordinated emergency planning between the different blackout planning roles namely [2]:

- *The Power System Black-Start Plan*
- *The Utility Blackout Plans*
- *The Country Blackout Plans*
- *The Regional Blackout Plans*

Given the emergency planning roles, the utility emergency response structures require defined emergency objectives to steer, coordinate and direct the response and recovery of operations. **Table 1** tabulates Eskom's blackout response objectives during the response and recovery.

Table 1: *Description of Eskom's response and recovery objectives* **[2]**

#	Eskom Blackout Response Objectives	Description
1	**Contain the incident and enable system restoration**	• *Successful operation of automatic systems (unit islanding) and/or black-start facilities* • *Rapid incident assessment and blackout declaration* • *Activation and mobilisation of response systems (golden hour)*
2	**Securely restore the national power system**	• *Restoration of the power system in a deliberate, secure manner (to avoid a subsequent blackout during restoration)*
3	**Ensure the safety of personnel, plant, systems and the environment**	• *Preservation of generation units and nuclear safety* • *The safety of Eskom responders and general staff* • *Operating plant within thermal limitation* • *Safe shutdown of non-essential systems Manage environmental violation*
4	**Support the country and region's blackout response**	• *Coordination with national and provincial emergency response structures* • *Liaising with Government* *Invoking contingency arrangement with key role players*
5	**Ensure the continuity of identified critical**	• *Continuity of mission critical processes and operations* • *Safe recovery of non-essential applications*

#	Eskom Blackout Response Objectives	Description
	operations and staged recovery of all operations	• *Recovery business operations to deliver product and service*
6	**Recover Eskom's reputation and stakeholder confidence**	• *Demonstrate an effective technical and crisis communications response to all identified stakeholders* • *Support country communication and stakeholder management.*

5.3 BLACKOUT RESPONSE PRINCIPLES

The establishment of blackout principles provide a basis for planning across operations to ensure the harmonisation of technical switching plans between generator, transmission, distribution and large power users. It requires the determination of a detailed procedure on how to restart the IPS. This is crucial for the identification of the following: (i) potential threats and vulnerabilities, (ii) the sequence of the restoration, and (iii) the mobilisation of resources to prioritised power stations, transmission and initial customer loads. This would include the following restoration principles during the normalisation of the interconnected power system:

- Islanded generator units or black-start units supply auxiliary loads at power stations.
- The priority is to build network "rings" that allow N-1 operation of the small islands created by matching local load to these generators to create a super highway that connects all the power stations together in the most efficient way (taking voltage stability into account).
- The load picked up will be determined by the System Operator based on what is best for the stability of the system.
- The initial priority will not be to supply power to essential and critical loads or specific areas, and supply will be restored to blocks of residential customers considering the resistive nature of the load due to predictability and the ability to damp voltage swings.
- The speed of restoration of the power system is dependent on availability of the transmission network and the state of the generator units, e.g. hot, warm and cold starting (Cold starting a large coal fired generator can take over 16 hours). However, the speed of restoration is secondary to making absolutely sure that the islands are formed and operated in a safe and secure manner.
- Multiple islands will be energised simultaneously and synchronised. The reconnection of islands will only be possible with a stable N-1 configuration power system.
- Should islanding of the generators fail, Eskom has licensed black-start facilities and would require at least one to restart the IPS.
- Eskom's nuclear power station will remain on line if it did not trip. The safety of the nuclear station will be the first priority, with dedicated on and offsite generators automatically responding to ensure adequate electrical supply as required by the nuclear regulator. Its role in maintaining an island in the Western Cape will be determined by nuclear safety technical limitation.

The integration between technical and non-technical considerations and appropriate risk taken to restore the IPS will require the evaluation of vulnerabilities and enhance coping capabilities by reviewing the risk controls and treatment plans across the utility. Furthermore, due consideration should be given to enhancing the resilience of the telecommunication infrastructure, integration with country emergency structures, country response partners and enhanced crisis communication protocols.

5.4 BLACKOUT (NON)-TECHNICAL CONSIDERATIONS

The blackout technical restoration plan must be in place to restore the power system with due consideration for technical constraints and plant/equipment threshold. The power utility is responsible to ensure an efficient, but safe and reliable restoration of the power grid after a blackout. The following non-technical and technical considerations should be evaluated to determine the restoration procedure of the IPS.

5.4.1 Non-technical considerations:

- Control Centre staff must be skilled in the execution of the plan and undergo regular refresher training on execution of the black-start and islanding plans.
- The load requirement rules are determined by National Control (NC) and distributors to ensure that the smaller and larger load block requirements are to be catered for if not limited by the restoration area due to not having the required load available.
- Each Control Centre will be responsible for the safe operation of the network under their control under instructions from NC. Some of the responsibilities are as follows:
  - *Clear role clarity and duties defined between control centres.*
  - *Carry out sectionalising on the network which is under their demarcation in support of the integrated restoration plan.*
  - *Liaise with all municipalities under their control area and give feedback to NC on sectionalising and load restoration.*
  - *The integration of the restoration plan is to be extended to the large metros as a large amount of South Africa's resistive load is embedded within electricity networks of these metros.*
  - *To liaise with top customer representatives in their control area and give feedback to NC.*
- It is prudent to exercise the integrated technical restoration plan and emergency response structures (such as Incident Command Systems).
- The restoration plan should be dynamic to changing conditions to ensure that almost all contingency scenarios are catered for.
- Environmental management constraints will not apply, however an agreement with authorities is necessary.
- Ensure safety of staff and equipment by controlled plant shutdown, as per the expected technical and situational response capability.
- Liaising with national security agencies and structures to protect critical corridors and networks.

5.4.2 Technical considerations:

- **Load Type:** During the initial restoration phase, resistive load is considered as first priority due to the behavioural predictability of this load type and the acceptable power factor.
- **High Frequency:** It is always good to run the frequency a little on the higher side when restoring load, however it must still be kept to within limits. This is done in anticipation of a rapid frequency drop on pick-up of a load-block.
- **Frequency Control:** It is recommended that one or two of the fast response generators do frequency control and the others stay on base load.
- **Cold Load Pickup:** The phenomenon that takes place when a customer load is re-energised following an extended outage of that circuit. Cold load pickup is a composition of two conditions: inrush currents and loss of load diversity. This combination can result in current levels that are significantly higher than normal peak load levels. Cold load

pickup current can be high enough to cause instantaneous overcurrent and/or time overcurrent relays to operate.

- **Stability:** The ability of the system, for a given initial operating condition, to regain a normal state of equilibrium after being subjected to a disturbance.
- **Generator Loading:** Generator ramp rates vary from station to station and are dependent on the type of boiler, how long the unit was off load for and the time taken to put in mills.
- **Automatic Generation Control (AGC):** will not be available for the duration of the restoration process. Frequency control will be done manually.
- **Generator reactive limits** need to be monitored to ensure that the generator does not operate at its limits in lagging and leading ranges.
- **Synchronising of generators:** When generators are to be synchronised onto the island, the island frequency must be reduced to below 50 Hz before the new generator is synchronised. This can prevent a high frequency event in case the generator is synchronised at a high load.
- **Pumped Storage Generators:** These generators should be used for frequency control in their respective islands. There are cavitation limits at these stations, and it is recommended not to run within these limits but to run through them.
- **Energy requirement for safe shut-down:** Generation unit preservation actions to enable and ready the plant from forced shutdown to a start-up readiness state include the ash removal systems, lubrication, demineralised water, regulatory requirements, etc.
- **Independent Power Producers:** SAGC requires all IPPs to remain off-load when no voltage is seen on their respective bus-bars. IPPs should liaise with their respective control centres, and remain off-load until further notice.
- **Power Angle between Islands:** During the interconnection the power system angle will be considered (wherever possible) when synchronising between islands. Transmission line breakers have synchronising capability built into their protection system to minimize closure at large power angles.
- **Bulk water and coal distribution:** Due consideration should be given to ensure that fuel (coal) and raw water are available to site, thus not covered by Gx, beyond exposure monitoring
- **Substation switching:** Substations must be prepared and sectionalised before re-energisation of the substation or network. The preparation of the substations is dependent on line lengths and voltage control within the respective network.
- **Substation Transformers:** During substation preparation, the transformer that supplies the substation auxiliary load is to be energised first (if possible). The DC conservation plan is to be invoked to extend the battery time.
- **Power lines auto re-closure settings:** During initial restoration, all ARC relays must be selected to single pole ARC and if the line does not have single pole tripping the ARC must be set to manual.
- **Voltage control:** Voltage control during system restoration is much more complex as compared to voltage control in a healthy system. In a healthy system, the fault level is high at stations near or at power stations and reduces as one goes away from the power stations. The fault level of the system is dependent on the number of generators connected to that system. During system restoration, the fault levels are at minimum during the initial phases of restoration. This is due to the limited number of generators connected to the grid at the time. The fault level increases as each generator synchronises to the island.

- **Reactive devices:** With this low fault level, care needs to be taken when doing voltage control, because a small change of reactive power (MVArs) will result in a high change of voltages. Reactive power devices such as capacitors and static VAr compensators (SVC) will behave differently during system restoration due to the lower fault levels. Reactors will be used during the initial stages of restoration to minimize high voltages.
- **Returning a line to service:** The line must be closed in from the side with the higher fault level. This is done so that there is minimum impact on the change of voltages and less stress to the system. Also note that the single-ended charged lines act as capacitors to the busbars that they are connected to which will result in high voltages.
- **Surge Impedance Loading:** When transmission lines are lightly loaded, they will act as capacitors and generate MVArs. This will in turn increase the voltages in the surrounding network. During initial restoration, most lines will be generating MVArs.
- **Line length:** when restoring a substation after a fault or even after returning a line from maintenance, the line length plays an important role. The line lengths affect the Ferranti voltages and one need to keep that in mind during restoration. To energise a substation after an interruption, the shortest line into that substation must be used. This minimises the change of voltages as a result of the line capacitive charging current. The restoration should start with lower voltages. This is to minimise the high voltage at the receiving ends of lines due to the Ferranti effect.
- **Non power station ends first:** lines that are connected to power stations are always closed in from the remote side. This is done to eliminate any undue stress on the generating units in case a fault occurs on the line.

6. BLACK-START FACILITIES

Utilities are able to deploy a number of black-start facilities to reduce the restoration time and/or support the IPS during the recovery to a normal state. The key priority for the System Operator is to establish and restore a stable power system using the islanded generation units and/or black-start facilities available at the time and due consideration shall be given to safety of personnel and plant. The power system manager has the authority to carry out actions to ensure the stability, integrity and safeguard the IPS, especially preventing a national blackout incident.

6.1 ISLANDING SCHEME

South Africa is isolated from other Southern African power pools of sufficient size to restart one of Eskom's generators and for this reason a number of generators have islanding capability. The ability of generators to continue operating when separated from the grid will significantly reduce the IPS restoration time, rather than waiting for the many hours necessary to start up a black-start machine (because islanded units are already on load and supplying their own auxiliaries).

6.1.1 Grid Code requirements

Generator units that do not have black-start or self-start capabilities must island when required (if technically possible). This capability is limited to generator units with a rating greater than 200 MVA.

The ability of these units to island needs to be tested according to the SAGC criteria. Therefore, generator unit islanding tests are regularly conducted and certified for islanding based on the outcome of these tests. The capability to island units from the IPS at full load would require automatically maintaining the turbine in a stable mode at desired speed, excitation and supplying the auxiliaries without external supply.

Contracting generator units to provide the unit islanding capability outlines the rules and regulations under which the service shall be provided so as to ensure the safe, stable and reliable operation of the network. Upon completion of contracting, the service is periodically monitored to ensure that the capability is always in a state of readiness and availability in the event of a system incident/blackout.

6.1.2 System Operator islanding units requirements

- The ancillary services technical requirements (ASTR) documents the functionality that equipment (predominantly generators), connected to the network must provide to ensure system security. This includes requirements such as reserves, reactive power, islanding and others.
- The load pickup of the islanded unit shall be executed under the instruction of NC on what is appropriate to maintain a semi-stable island.
- The System Operator shall witness the islanding test to provide independent certification of units.
- Generator to submit a report after a successful test or incident within six weeks.
- Ancillary Services would adhere to procurement and contracting processes to ensure that the cost associated with availability, certification, testing and performance monitoring supports system reliability objectives.
- Ancillary Services would periodically monitor the compliance and performance of generators capability to maintain the islanded condition.
- Exemptions and expired certification of islanded units shall be monitored by System Operator and Generation. Assurance should be provided to address violation and possible compromises conditions that maintain influence the capability of unit to island.
- Generation business shall provide assurance of the training of personnel to conduct unit islanding to ensure the success of the islanding.
- During an actual restoration, System Operator can instruct islanded units to safely shut down considering the sequence of restoration (requiring plant preservation actions, controlled shutdown, to enable and ready the plant from a forced shutdown to start-up readiness state).

6.2 BLACK-START FACILITIES

Black-start capability is the ability to self-start, supply auxiliaries and light up a unit, which will then energise a defined portion of the transmission system such that it can provide the start-up energy required for other base load generators connected to the system. The Eskom grid topology makes black starting the system technically difficult because of the centralised generation pool and the very long transmission lines. Black-start capability is an insurance policy in response to an unlikely sequence of failures of Eskom’s defence systems following a severe disturbance.

6.2.1 Grid Code requirements

In the event of unsuccessful unit islanding, facilities must be in place to restart the national power system. The facilities used to black-start the system must be available when called on by the System Operator. These units are regularly tested in terms of the requirements of the SAGC. The power system is operated and maintained in such a manner that at least one of these units is available at all times. Protocols are in place to ensure that the power system is operated in such a manner to ensure that the resources required by these facilities are not compromised.

Although unlikely, the possibility exists that no generators will be islanded. In terms of the SAGC, two facilities should be available which can both self-start without auxiliary power (i.e. external grid support). These can provide enough power to the auxiliaries of a neighbouring power station so that it can be restarted. This is the initiation of the black-start process. These facilities are tested regularly according to the SAGC requirements

- *The SAGC requires that there be at least two suitable BS facilities at different locations in the system*
- *The System Operator shall determine the minimum requirements for a BS facility before contracting*

- *To prove the capability of the system, the System Operator shall perform partial and full black-start tests periodically (every 3 to 6 years) as required by the SAGC.*
- *Due diligence to be exercised as part of test preparations i.e. planning and studies to be performed prior to the partial or full BS facility test.*

6.2.2 System Operator black-start facility requirements

- *Geographical location of a unit capable of black starting has to allow for restoration without technical constraints.*
- *Each blackstart facility shall be available at least 90% of the year as long as maintenance and repairs are coordinated such that there is at least one facility available all the time.*
- *A thermal power station shall be capable of self-starting at least one unit after a forced shut down without support from the external grid*.
- *The first unit shall be capable of energising a portion of the power system within four hours of shutdown*.
- *Skilled generation personnel capable of black starting and controlling a generator during restoration.*
- *Units contracted for black-start shall be capable of providing sufficient reactive power support to control the declared transmission voltages between ±5% of nominal voltage.*
- *There shall be sufficient water/fuel for three black-start attempts on the unit at all times and shall be capable of sequentially black starting a unit up to three times.*
- *After black-start, the power station must be capable of reenergising a part of the Transmission/Distribution grid within a specified time.*
- *The reactive capability to charge the immediate Transmission/Distribution System. (100 MVArs leading) and to absorb reactive power due to the Ferranti effect. (Capacitive effect - 100 MVArs lagging)*
- *The generating unit must be capable of instantaneously picking up load blocks within a specific range (30 to 50 MW).*
- *The power station must be capable of controlling the frequency within a specific range, and keeping the voltage within acceptable limits during the pickup (block loading) process.*
- *A pumped storage/hydro station shall be capable of self-starting one or more units, energising a part of the grid (line to a thermal station) and so providing auxiliary power to enable a thermal unit to start within four hours of the shutdown of the thermal unit.*

6.3 NUCLEAR SAFETY

An important risk in relation to a national blackout is that of nuclear safety. For this reason, the priority for the nuclear power station is to ensure nuclear safety during a blackout. The blackout restoration plan for this reason does not rely on the use of the nuclear power stations.

6.3.1 Management of Nuclear Incident

The decision to safely shut down nuclear generating units lies with the power station and not with the System Operator. Nuclear station is self-sufficient with a dedicated off-site supply as per nuclear regulation. The coordination of plans and response procedures is addressed in the nuclear plant emergency plan, including the impact of possible external threats (e.g. HILP) on grid supplies to station. Thus, a nuclear emergency could require an emergency response by several internal and external government organisations.

The responsibilities of national, provincial and local intervening organisations relating to nuclear emergencies are addressed in the Disaster Management Act, 2002 (Act No. 57 of 2002) and the National Nuclear Disaster Management Plan.

The responsibilities of Eskom and the National Nuclear Regulator relating to Integrated Koeberg Nuclear Emergency Plan are addressed in the National Nuclear Regulatory Act, 1999 (Act No. 47 of 1999).

The management of the emergency activities is prescribed by the nuclear work flow responsibility matrix. Therefore the nuclear safety requirements would focus on the grid operability before reconnecting a nuclear station to the IPS during a national blackout incident.

6.3.2 Grid operability for a nuclear station

The grid operability has been derived from the National Nuclear Regulator and international accepted practices. It defines in general, the specific technical criteria for declaring the grid operable. Therefore depending on the plant status and network configuration the nuclear station may resynchronise to a limited 400kV grid.

6.4 INDEPENDENT POWER PRODUCERS (IPPS)

Once a need for additional black-start facilities has been identified, technical studies will have to be carried out to find the most advantageous locations for a new BS facility. If a new or existing IPP (with BS capabilities) is operating in that region, then it can be considered as a potential blackstart service provider.

The procurement of IPPs for black-starting will follow the same process as that of the Eskom generation fleet. To this end, facilities must satisfy both the SAGC and ASTR to be considered for providing the service.

6.5 OCGTS

An Open Cycle Gas Turbine (OCGT) has the ability to self-start, however there are no thermal power stations in close proximity to energise during the restoration. Fuel capacity and availability of the OCGT should be carefully managed during a blackout incident. The technical constraint of smaller generator units has reduced expectation for the reliability, operation and capabilities (e.g. power and reactive stability support during blackout recovery, due to long transmission).

7. CONCLUSION

The planning to respond to a major electricity-related incident requires the establishment of a number of capabilities to prevent and respond to a national blackout incident. The obligation of utilities is prescribed within the Disaster management Act and Southern Africa Grid Code. These regulatory instruments require utilities to plan for a range of contingency scenarios, including those that have a high impact but a low probability of occurring.

This paper focuses describing the blackout recovery phases and planning required for responding to a national blackout incident. It provides a numbers of aspects a system engineer should consider when compiling it technical blackout restoration plan, such as: recovery mechanisms, response objectives, principles and technical consideration.

Furthermore the paper discusses the grid code and system operator requirements for the black-start facilities. The paper concludes with a discussion on the nuclear safety, IPP and OCGTs consideration in the evaluation of the technical restoration plan.

8. ACKNOWLEDGMENTS

The authors acknowledge the Eskom National Blackout Working Group and System Operator for guidance and support and also acknowledges the co-authors’ contribution to the paper.

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