Black Start Study Report

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EXECUTIVE SUMMARY

The current ERCOT Black Start procurement process begins with a request for proposal (RFP) soliciting responses from Resource Entities interested in providing black start service. A non-optimizing sequencing tool is used to analyze the received bids to determine the most cost effective combination of black start units. A study commissioned by ERCOT in 2014 (performed by NEXANT) to review the readiness program, provided several suggestions to improve the procurement process, important among them being the need for clearly defined islands and an optimizing tool for determining the units and/or sites best suited to black start service, including those that may not currently be black start capable but could be incented to add this capability, and their corresponding cranking sequence.

Using these recommendations as a basis, ERCOT has conducted black start resource analysis for the ERCOT system using the Optimal Black-Start Capability (OBC) tool from Electric Power Research Institute (EPRI). The ERCOT grid was divided into islands based on different criteria like load centers, proximity to critical loads and location of nuclear generation sites. In each island, feasible resources were then tested for black start suitability. All tested resources were evaluated based on the load and energy restored, as well as the speed with which a stable load-generation balance was reached as determined by an AC power flow solution constrained by limits on bus voltage.

The results of the analysis, listing the units that were found to be reasonable options to consider to provide black start service in each island, are provided in this report.

1. Introduction

Black Start is the process of recovering from a total or partial shutdown of the transmission system which has caused an extensive loss of power supplies. In this process, the Black Start generator is required to provide start up power to other power stations when the system restoration begins and establish a stable island. The island so formed, will eventually be required to synchronize with other power islands.

To facilitate this, the Black Start Service (BSS) is procured from generators that have the capability to start main blocks of generation from an on-site auxiliary generator, without reliance on external site supplies. In the event of a Black Start, the service requires the provider to start up its main generator(s), carry out initial energization of sections of the Transmission System and distribution network in coordination with the transmission service provider (TSP) and, support sufficient demand to create and control a stable power island.

1.1. The Black Start procurement process

The current ERCOT Black Start procurement process begins with a request for proposal (RFP) soliciting responses from Resource Entities interested in providing black start service. Timely submissions are accepted and then analyzed using an in-house tool written in Matlab™. The program uses sequential start-up to build each island (number of islands equaling the count of BSUs) –

a. Each unit must reach 80% of capacity before next unit is started.
b. Build-out proceeds in “multiple” directions based on transmission line data.
c. Transmission line data is strictly used for connectivity to next start unit and to test for distance between the last unit and the next-next start unit
d. A fixed speed is assumed for travelling crews.
e. Back-up battery power for SCADA is not considered.
f. Once all islands are analyzed, the largest island restoration time is reported.

The results are analyzed and the proposed set of BS units that minimizes cost and restoration time is determined. The selected units are then examined for black start feasibility (through simulations), though cranking path analysis not performed by ERCOT. Final selections are then made and the selected BSUs must successfully complete the testing as required by the ERCOT Operating Guides.

After the testing is completed, the black start plans of the TSPs are updated to reflect the current set of BSUs. The TSPs perform cranking path analysis as needed. After ERCOT approval and posting, the Black Start resource owners sign Black Start Agreements and the plans are implemented on January 1st of the coming year.

1.2. NEXANT Recommendations on procurement

The NEXANT study report identified several issues with the current procurement process and tools. The analysis covered the entire process including the bids received, the studies to determine the final set of procured resources and the duration of the offered contracts. The issues are as follows –

a. Reduced interest in BSS contracts. Reasons for reduced interest in bidding for Black Start contracts –
    i. Prohibitive entry/set-up costs

ii. Topology Changes

b. No clear reasoning for the number of islands employed other than historical and the number of procured resources
c. Non-optimizing analysis tools for BSS
    i. Non-optimized Black Start cranking sequence
    ii. Lack of power flow solution in BSS analysis tool
    iii. Potential to procure units that are in an unhelpful location.
d. Biennial selections are the same cycle-to-cycle due to limited number of bids
e. The two year contract is insufficient time for units to recover the cost of adding Black-Start capability

To address these issues, the report from NEXANT made several proposals, of which the ones relating to the procurement studies are listed here.

a. Defining islands in a way that leads to faster load recovery rather than in reaction to unit selection. Items to consider –
    i. Load centers
    ii. Proximity to nuclear power plants
    iii. System topology
    iv. Sync-check relay locations
b. Conducting a Black Start Capability study of the system with the aim of generating a ranking of resources.
c. Use an optimizing software to determine the cranking sequence in coordination with the TSPs:
    i. Optimal Black Start Capability (OBC) tool from EPRI
    ii. Select primary and alternative Black Start units based on locations
    iii. Valid power flow solution of intermediate system states with no violations

1.3. Islands

In the current black start study process, there is no clear reference to what an island is and whether or not such an island meets any minimum criteria for stable energization and synchronization. As such, there are also no criteria for the number of islands that should be formed and where and when they need to be tied together. So far, the black-start units (BSUs) and their associated cranking paths have been used as the basis for the islands.

In order to define islands for this study, the motivating assumption was that load centers would be good locations for a black start unit, with the requirement that nuclear generation sites have off-site power restored in 4 hours after a black out being a critical constraint. Near or within a major load center, there would be,

a. high opportunity for rapid load pick-up allowing restoration to quickly proceed to a stable island frequency, and,
b. from a study perspective the crew travel times within city limits can be quite short meaning that any assumptions we would make about the time taken for switching in lines and transformers would not carry as much of an error.

Therefore, each of eight load centers in the ERCOT region were defined as an island.

a. The proposed islands:
    i. Dallas/Fort Worth
    ii. Central Texas (San Antonio, Austin etc.)

iii. Houston
iv. Corpus Christi
v. Valley
vi. Laredo
vii. West Texas
viii. Far West Texas

b. Some of the load centers were split up into two or more sub-islands to meet set constraints.
c. In some of these cases (particularly the smaller load pockets), reasonable BSU candidates were found outside the physical island. The island definition in these cases, was extended to allow the external candidate to participate in the restoration of that island.

1.4. OBC tool

The Optimal Black-Start Capability (OBC) tool estimates the effectiveness of a black start unit (BSU), in terms of the time to crank non-black-start units (NBSUs; 'crank' here means the process of starting the aux load of an NBSU using power supplied by another generator) and total available generation capability. Based on the issues of generator start-up sequencing and transmission path search, and taking into account the time to connect NBSUs, the optimal installation of BS capability is formulated as an Integer Programming (IP) problem. The solution of this optimization problem is the quantification of the benefit of optimal BS capability in terms of reduced restoration time and increased generation capability. There is, of course, an upper bound beyond which system restoration time cannot be further reduced by adding BS capability. The OBC tool provides results which can assist system planners in making decisions regarding these issues, in terms of the location and size of additional BSUs. The following data set is required for the OBC tool:

a. Topology and parameters of a power grid.
    - The data items are provided by PSS/E data file (*.raw)
b. Characteristics of each generating unit
c. Characteristics of each load
d. Characteristics of each line
e. Characteristics of each transformer

The OBC tool splits the analysis of the black start sequencing into three stages. From EPRI's report on the tool, the stages are –

a. Generator start-up sequencing (mixed-integer programming via CPLEX)
b. Establishment of transmission system (power flow simulation via OPF).
c. Load restoration (also via OPF)

Figure 1 below shows a representation of the three stages and details about them.

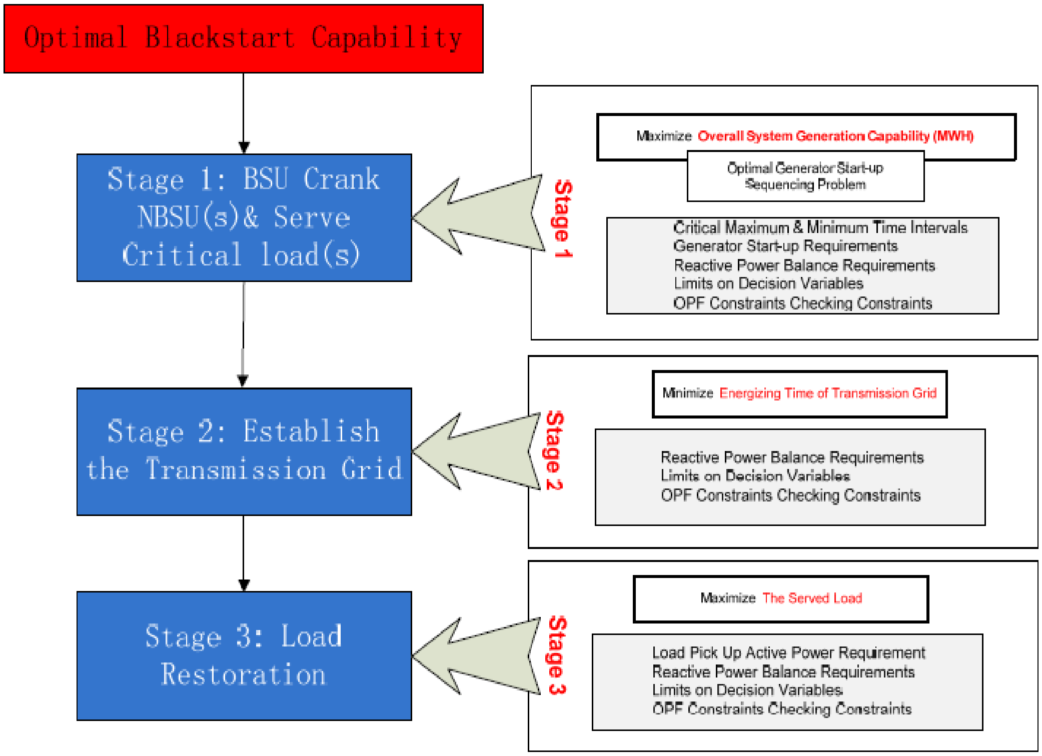

Fig 1: Optimal Black-Start Capability analysis – the three stages (*Source*: EPRI OBC v2 User Manual, 2015)

2. Study Process

This study is aimed at determining the suitability of existing resources on the ERCOT system for the black start service. The OBC tool provides a means to determine the optimal cranking sequence for any generator when used as a black start resource, and simulates the energizing of the transmission grid and load pick-up. The results can therefore be used as a metric to check the effectiveness of the resource at restoring its island. The following assumptions are made regarding the system and the resources –

a. This study is for the scenario where a system event caused the black out. Ergo, all facilities are expected to be available for the determination of optimal sequencing and simulation of restoration actions.
b. Resources using coal, nuclear, wind and solar power are not analyzed in this study for suitability to black start service.
c. Resources inside Private Use Networks and asynchronous ties (DC, VFT etc.) to neighboring systems are also not included in the analysis.

Since this study is an exercise to determine suitability of existing generation resources to black start service from a network restoration perspective, no assumptions are made about the capability or lack thereof of any resource for providing black start service. All applicable resources being tested (see point 'b' above) are assumed to be black start capable for this study.

2.1. Study Inputs

This study requires system topology, generator start-up (hot/cold) times, load data and island information. Power flow data in PSS®E RAW (v. 30) format is used to provide the network and load information and an excel spreadsheet is used (format specified by EPRI) to provide –

a. Generator data
b. User Parameters
c. Load Data
    - The tool allows the user to distinguish between critical and non-critical loads. Where the information was available from TO black start plans, critical loads like compressor stations, hospitals etc., and nuclear generation site auxiliaries as well, were marked as critical to prioritize their pick up.
d. Line switching times

2.2. Generator Parameters

The following parameters form the input Generator Data for the OBC tool (taken from the RARF for each generator):

a. Time for a generator to parallel with the system, Tp
    - It indicates how soon a generator can parallel with the system after it is energized.
    - HOTSTART from the RARF is used for this data.
b. Critical minimum time interval of a Non-Black-Start Unit NBSU, Tcmin
    - A generator with a supercritical boiler has a minimum cold-start time, i.e., Tcmin. The generator cannot be cranked until the minimum critical time elapses.
    - MIN_OFFLINE_TIME from the RARF is used for this data.
c. Critical maximum time interval of an NBSU, Tcmax

- Most NBSUs in the power system are thermal generators. A generator with a drum type boiler has a maximum startup time, i.e., Tcmax. If the generator is not restarted within this time, its start-up has to be delayed by a considerable time period. Tcmin should be less than Tcmax for any generator. An NBSU can be started between its Tcmin and Tcmax.
- This data is calculated for each generator as the sum of its HOT_TO_INTMDT_TIME and INTMDT_TO_COLD_TIME.

d. Maximum ramping rate of a generator, Ramp.
   - HR_RAMPRATE_LMT from the RARF is used for this data.

e. Cranking power requirement of a generator, Pstart (MW).
   - AUX_MWTOTAL from the RARF is used for this data.

f. Capacity of a generator, Pmax (MW).
   - From the RAW data
   - Adjustment made to model gross MW if station load is not in the PSS®E case.

g. Minimum reactive power output of a generator, Qmin (MVar).
   - From RAW data

h. Maximum reactive power output of a generator, Qmax (MVar).
   - From RAW data

3. Study Results

The study process involved generating an optimal cranking path, including energization time of each element on the path, for each tested resource (CPLEX). Then an optimal power flow was formulated and solved (OPF) for the generated path over the duration of the simulation. Constraints on bus voltage, and active/reactive power balancing were applied as part of the OPF formulation and load pick-up was simulated to allow constraints to be met.

Solutions to both aspects of the process – CPLEX and OPF – were evaluated for each resource and the results for all tested resources are provided in this section.

1. CPLEX Unsolved: An optimal cranking path was not found that met the set constraints of the study (generator start-up times, ramp rates and element switching times etc.).
2. OPF Unsolved: The calculated cranking path return a diverged power flow solution and/or violated constraints when simulated in the OPF.
   a. Bus voltage constraints of 0.9 – 1.1 per unit were used as standard for the study.
   b. When OPF was unsolved, these constraints were relaxed to 0.8 – 1.2 per unit to check whether the issue was sustainability of voltage.
   c. OPF was marked as unsolved if convergence failed for both standard and relaxed voltage constraints.

3.1. Dallas/Fort Worth

This island was studied as the combination of two smaller sub-islands, designated 'DFW West', and 'DFW East' for the purposes of this study. The list of tested resources in these sub-islands and their results are provided below.

3.1.1. DFW West

Each of the following resources were found to have potential as a black start resource, for restoring generation and load in this island:

Site	Resource
Decordova (DCSES)	CT10, CT20, CT30, CT40
Wolf Hollow II (WHCCS2)	CT1, CT2
Tenaska TMPP (TEN)	CT1
Wolf Hollow Gen (WHCCS)	CT4, CT5
Handley (HLSES)	UNIT3, UNIT4, UNIT5
Graham (GRSES)	UNIT1
RW Miller (MIL)	MILLERG1, MILLERG2, MILLERG3, MILLERG4, MILLERG5
Wichita Falls (WFCOGEN)	UNIT1, UNIT2, UNIT3, UNIT4

3.1.2. DFW East

Each of the following resources were found to have potential as a black start resource, for restoring generation and load in this island:

Site	Resource
Forney (FRNYPP)	GT11, GT12, GT13, GT21, GT22, GT23

Lake Hubbard (LH2SES)	UNIT1, UNIT2A
Mountain Creek (MCSES)	UNIT6, UNIT7, UNIT8
Tenaska (TNSKA)	GT1, GT2
Panda Sherman (PANDA_S)	SHER1CT1, SHER1CT2
Denison Dam (DNDAM)	DENISOG1, DENISOG2
Lamar Power Partners (LPCCS)	CT11, CT12, CT21, CT22
Stryker Creek (SCSES)	UNIT1A, UNIT2
Trinidad (TRSES)	UNIT6
Freestone (FREC)	GT1, GT2, GT4, GT5
Tenaska Gateway (TGCCS)	CT1, CT2, CT3
Midlothian (MDANP)	CT1, CT2, CT3, CT4, CT5, CT6
Ennis Tractebel (ETCCS)	CT1
Engine (STEAM)	ENGINE1, ENGINE2, ENGINE3
Bosque Switch (BOSQUESW)	BSQSU1, BSQSU2, BSQSU4
Whittney Dam (WND)	WHITNEY1, WHITNEY2

3.2. Central Texas (San Antonio, Austin etc.)

This island was studied as the combination of two smaller sub-islands, designated ‘Austin’ and ‘San Antonio’ for the purposes of this study. The list of tested resources in these sub-islands and their results are provided below.

3.2.1. Austin

Each of the following resources were found to have potential as a black start resource, for restoring generation and load in this island:

Site	Resource
Decker Power Plant (DECKER)	DPG1, DPG2
Sand Hill Energy Center (SANDHSYD)	SH1, SH2, SH3, SH4, SH6, SH7
Decker Power Plant (DECKER)	DPGT_1, DPGT_2, DPGT_3, DPGT_4
Sand Hill Energy Center (SANDHSYD)	SH_5A, SH_5C
Sim Gideon (GIDEON)	GIDEONG1, GIDEONG2, GIDEONG3
Lost Pines (LOSTPI)	LOSTPGT1, LOSTPGT2
Winchester Power Park (WIPOPA)	WPP_G1, WPP_G2, WPP_G3, WPP_G4
Marshall Ford (MARSFO)	MARSFOG1, MARSFOG2, MARSFOG3
Ferguson (FERGCC)	FERGGT1, FERGGT2
Marble Falls (MARBFA)	MARBFAG1, MARBFAG2, MARBFAG3
Wirtz (WIRTZ)	WIRTZ_G1, WIRTZ_G2
Buchanan (BUCHAN)	BUCHANG1, BUCHANG2, BUCHANG3
Bosque Switch (BOSQUESW)	BSQSU1, BSQSU2, BSQSU4
Whittney Dam (WND)	WHITNEY1, WHITNEY2

3.2.2. San Antonio

Each of the following resources were found to have potential as a black start resource, for restoring generation and load in this island:

Site	Resource
Braunig (BRAUNIG)	VHB6CT5, VHB6CT6, VHB6CT7, VHB6CT8
Guadalupe Gen (GUADG)	GAS1, GAS2, GAS3, GAS4
Hays Energy (HAYSEN)	HAYSENG1, HAYSENG2, HAYSENG3, HAYSENG4
Rio Nogales (RIONOG)	CT1, CT2, CT3
Leon Creek (LEON_CRK)	LCPCT1, LCPCT2, LCPCT3, LCPCT4
Calaveras (CALAVERS)	OWS1, OWS2
Pearsall (PEARSAL2)	AGR_A, AGR_B, AGR_C, AGR_D

3.3. Houston

This island was studied as the combination of two smaller sub-islands, designated 'Houston 1' and 'Houston 2' for the purposes of this study, each representing South Houston (including STP) and North/Central Houston respectively. The list of tested resources in these sub-islands and their results are provided below.

3.3.1. Houston 1 (south, including STP)

Each of the following resources were found to have potential as a black start resource, for restoring generation and load in this island:

Site	Resource
Brazos Valley (BVE)	UNIT1, UNIT2
Colorado Bend II (CBECII)	CT7, CT8
Colorado Bend (CBEC)	GT1, GT2, GT3, GT4
W A Parish (WAP)	WAPGT_1
Victoria (VICTORIA)	VICTORG6
Sam Rayburn (RAYBURN)	RAYBURG7, RAYBURG8, RAYBURG9
Sky Global Power One (SKY1)	SKY1A, SKY1B
Texas Gulf Sulphur (TGF)	TGFGT_1

A test was run to determine the restoration time for STP from the resources within this island. Resources at BE, CBECII, VICTORIA and RAYBURN were able to successfully restore power to the auxiliaries at STP.

3.3.2. Houston 2 (north and central)

Each of the following resources were found to have potential as a black start resource, for restoring generation and load in this island:

Site	Resource
Airpro (AZ)	AZ_G1, AZ_G2, AZ_G3, AZ_G4
Pasgen (PSG)	PSG_GT2, PSG_GT3

Deer Park Energy (DDPEC)	GT1, GT2, GT3, GT4
Cedar Bayou 4 (CBY4)	CT41, CT42
T H Wharton (THW)	THWGT_1
Frontier (FTR)	FTR_G1, FTR_G2, FTR_G3
Sr. Bertron (SRB)	SRB_G1, SRB_G2, SRB_G3, SRB_G4
Channel View Cogen (CVC)	CVC_G1, CVC_G2, CVC_G3
San Jacinto Steam (SJS)	SJS_G1, SJS_G2
Greens Bayou (GBY)	GBYGT81, GBYGT82, GBYGT83, GBYGT84
Dansby (DANSBY)	DANSBYG2, DANSBYG3
Atkins (ATKINS)	ATKINSG7

3.4. Corpus Christi

A single island was sufficient for restoration of Corpus Christi. Each of the following resources were found to have potential as a black start resource, for restoring generation and load in this island:

Site	Resource
Barney Davis (B_DAVIS)	B_DAVIG1, B_DAVIG2, B_DAVIG3, B_DAVIG4
Nueces Bay (NUECES_B)	NUECESG8, NUECESG9

A test was also run to determine the restoration time for STP from the resources at Corpus Christi. Both units took approximately 4 hours and 20 minutes to restore power to the auxiliaries at STP.

3.5. Valley

A single island was sufficient for restoration of the Valley. Each of the following resources were found to have potential as a black start resource, for restoring generation and load in this island:

Site	Resource
Red Gate (REDGATE)	AGR_A, AGR_B, AGR_C, AGR_D
Silas Ray (SILASRAY)	SILAS_10
Duke (DUKE)	DUKE_GT1, DUKE, GT2
N. Edinburg (NEDIN)	NEDIN_G1, NEDIN_G2

3.6. Laredo

A single island was sufficient for restoration of Laredo. Each of the following resources were found to have potential as a black start resource, for restoring generation and load in this island:

Site	Resource
Laredo Energy Center (LARDVFTN)	G4, G5
Pearsall (PEARSAL2)	AGR_A, AGR_B, AGR_C, AGR_D

Amistad (AMISTAD)	AMISTAG1, AMISTAG2

3.7. West Texas

A single BSU was sufficient for the formation of a stable island in the West Central Texas region. Each of the following resources were found to have potential as a black start resource, for restoring generation and load in this island:

Site	Resource
Morgan Creek SES (MGSES)	CT1, CT2, CT3, CT4, CT5, CT6
Falcon Seaboard (FLCNS)	UNIT1, UNIT2, UNIT3

3.8. Far West Texas

A single island was sufficient for the formation of a stable island in the Far West Texas region. Each of the following resources were found to have potential as a black start resource, for restoring generation and load in this island:

Site	Resource
Ector County Energy Center (ECEC)	G1, G2
Odessa Ector (OECCS)	CT11, CT12, CT21, CT22
Quail Run (QALSW)	GT1, GT2, GT3, GT4
Permian Basin (PB2SES)	CT1, CT2, CT3, CT4, CT5

4. Conclusion

With the redefined study approach detailed in this report – islands based on load centers – and the OBC tool, ERCOT was able to identify multiple new units that have not historically participated in black start service which could potentially be useful during a black start restoration. The tools used for the study also identified the optimal sequence of restoration actions (i.e. the cranking path) for each tested resource, which can be a good starting point for development of restoration plans around these resources.