Role of energy storage systems in future power networks

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Overview of the Presentation

- Future power systems
- Role of ESS in future power system operation
- Examples of studies with ESS
- Summary

Projects on storage

RESTORES

UK and China collaborative project (1.1 million)

JUICE

UK and India collaborative project (10 million)

MY STORE

EPSRC project (1.2 million)

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Future power networks

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Renewable energy sources

The world added enough renewable energy capacity to power every house in the UK, Germany, France and Italy combined last year, according to a new report.(**Two-thirds of new power**)

161 GW cost about £187bn (23% cheaper than previous year)

The UK has first three coal-free days (10am 21st April – 10am 24th April), powered by gas, renewables and nuclear instead.

Renewable energy sources

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161 GW cost about £187bn … than previous year)

The UK has fi… ys (10am 21st April – 10am 24th April), … renewables and nuclear instead.

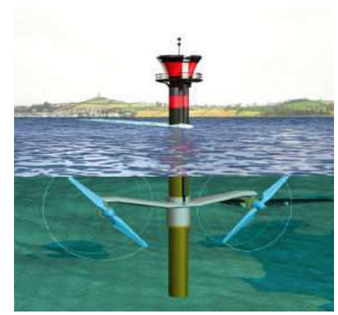
Wind farms were paid more than £100 million last year to switch off their turbines and not to produce electricity at the periods of low demand because Britain's electricity network is unable to cope high penetration of RES at low demand.

Categories of Renewable energy sources

Renewable energy sources

Synchronously connected

Converter connected interface



Intermittent and uncertain

Categories of Renewable energy sources

Renewable energy sources

Synchronously connected

Converter connected interface

Reduces the inertia of the system

Intermittent and uncertain

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Energy Storage Systems

Services provided by ESS

- ESS can provide congestion relief and postponement of grid upgrade.
- Peak shaving and standby reserves
- Integration of renewables
- Voltage support and frequency regulations

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Energy Storage Systems

Services provided by ESS

- ESS can provide congestion relief and postponement of [illegible]rade.
- Peak shaving and standby reserves
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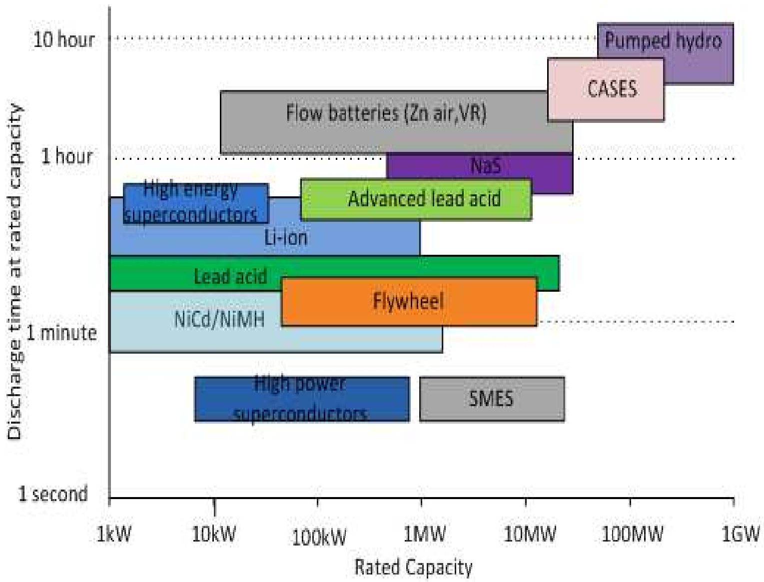
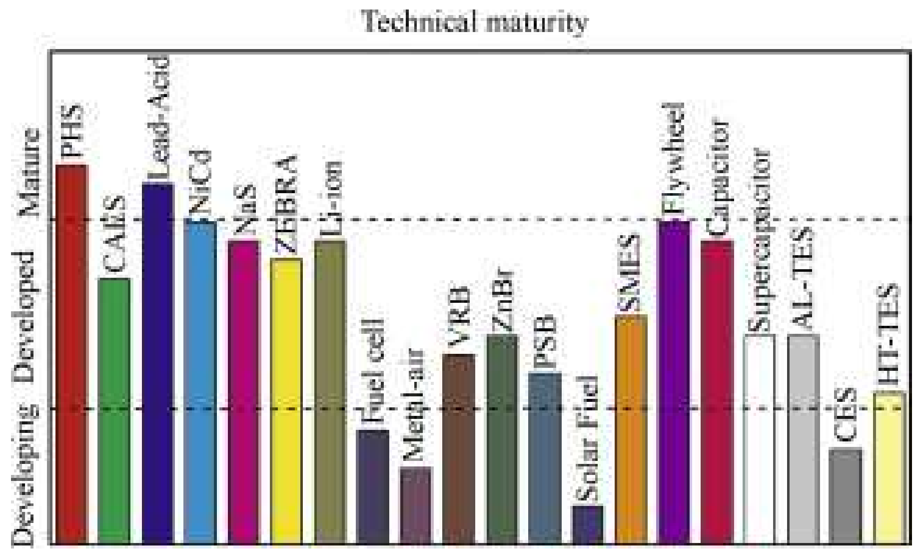
The UK could have 8-12 GW of ESS by 2021

Energy storage systems technologies





Since battery energy storage is the mature technology, we are currently using BESS in our studies. Though, the proposed frameworks and findings of the studies are equally applicable to any other ESS technology.

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Why we need new approach to grid frequency analysis with ESS

Traditional load frequency studies consider the collective performance of generators either by performing dynamic simulations or using analytical expressions.

In such cases, all generators in the network are aggregated into an equivalent generator with an inertia constant equal to the sum of the inertia constants of all generators, driven by the combined turbine mechanical output. The speed of this equivalent generator represents the system frequency.

- High penetration of RES changes the dynamic signature of the system
- The inertia the system also become heterogeneous due to high proportion of RES
- To compare support of centralized and distributed ESS
- To compare the effect of location of ESS on frequency support
- To include the effect of increased uncertainties in power generation and load forecast.

Examples Studies with ESS

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Comparison of dynamic models of battery energy storage for frequency regulation

We compared and evaluated frequently discussed battery energy storage system models to assess their suitability for frequency regulation studies

- Thevinen Model
- Battery Equivalent Circuits

-BES Equivalent Circuits with Converter

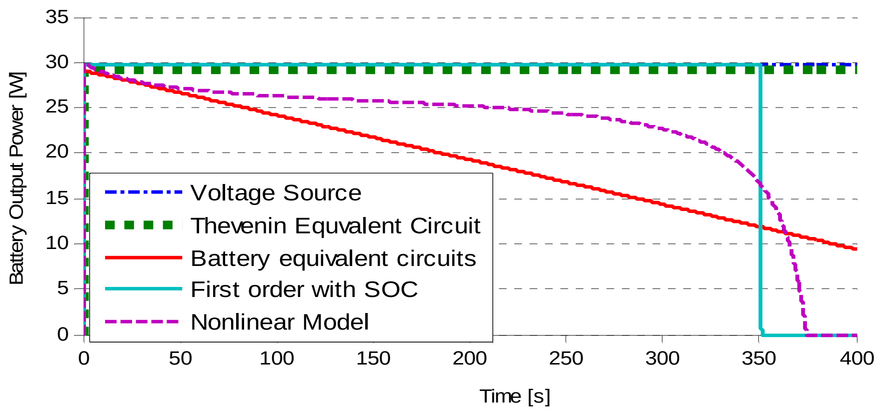
-Incremental BES Model

- Non-Linear Battery Model
- DC voltage source in series with a resistor

-First order Lag model

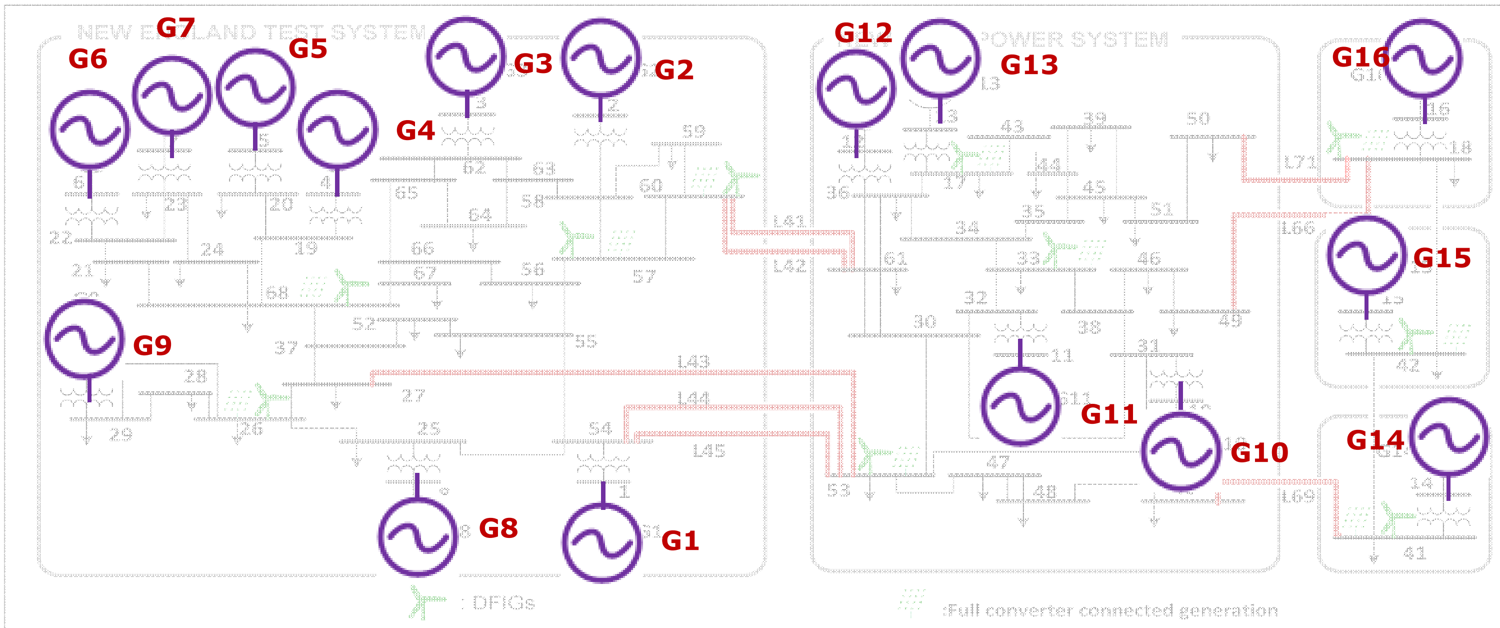
-First order model with state of the charge

Comparison of dynamic models of battery energy storage for frequency regulation



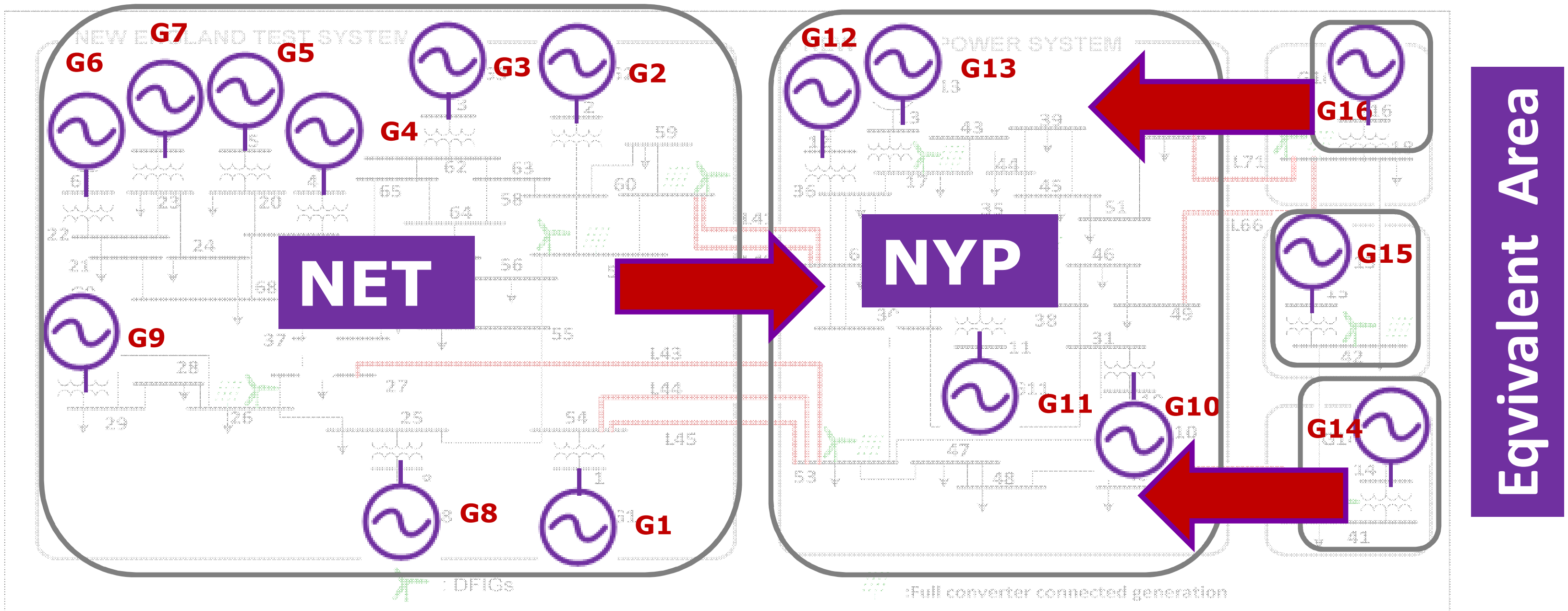
The most important battery parameters that can significantly affect frequency studies is the state of the charge. Other parameters like charging or discharging process, internal resistance and temperature dependency or converter model do not have any appreciable effect on frequency studies.

Test System



- 16 generators
- 68 buses

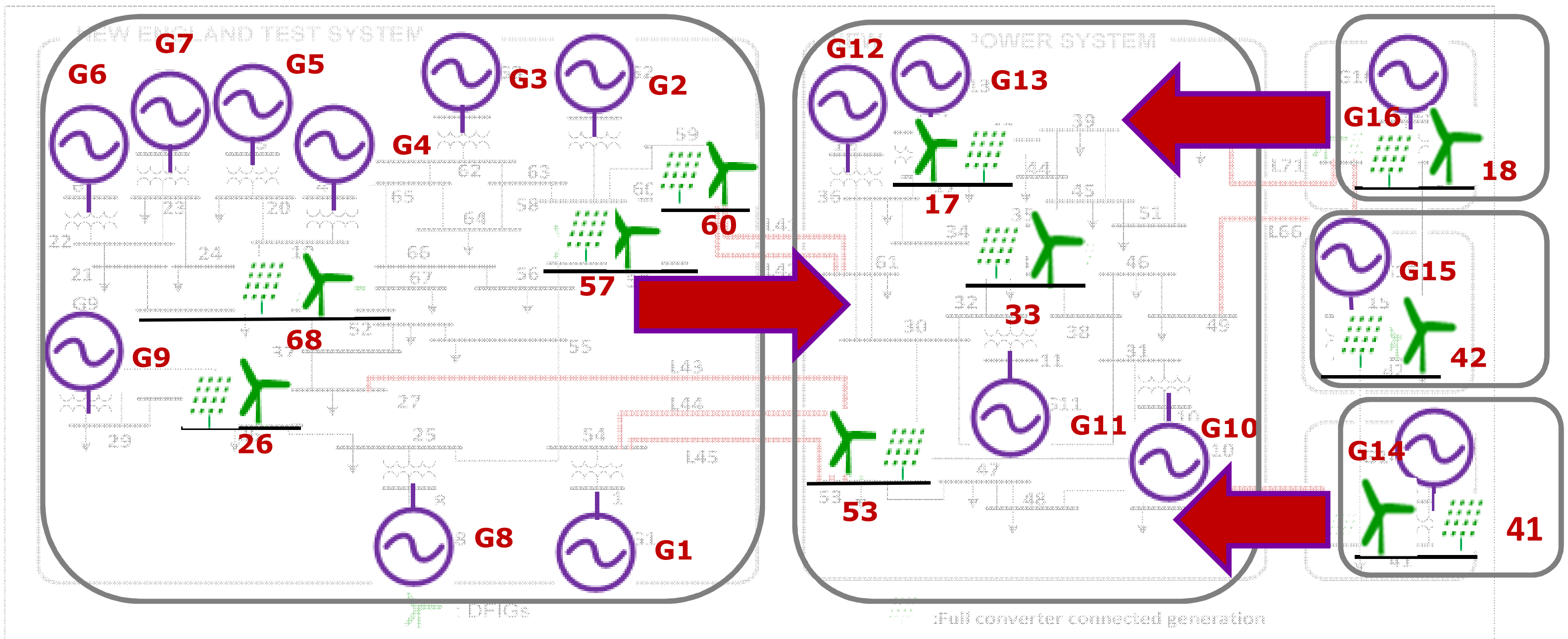
Test System



- 16 generators
- 5 areas
- 68 buses

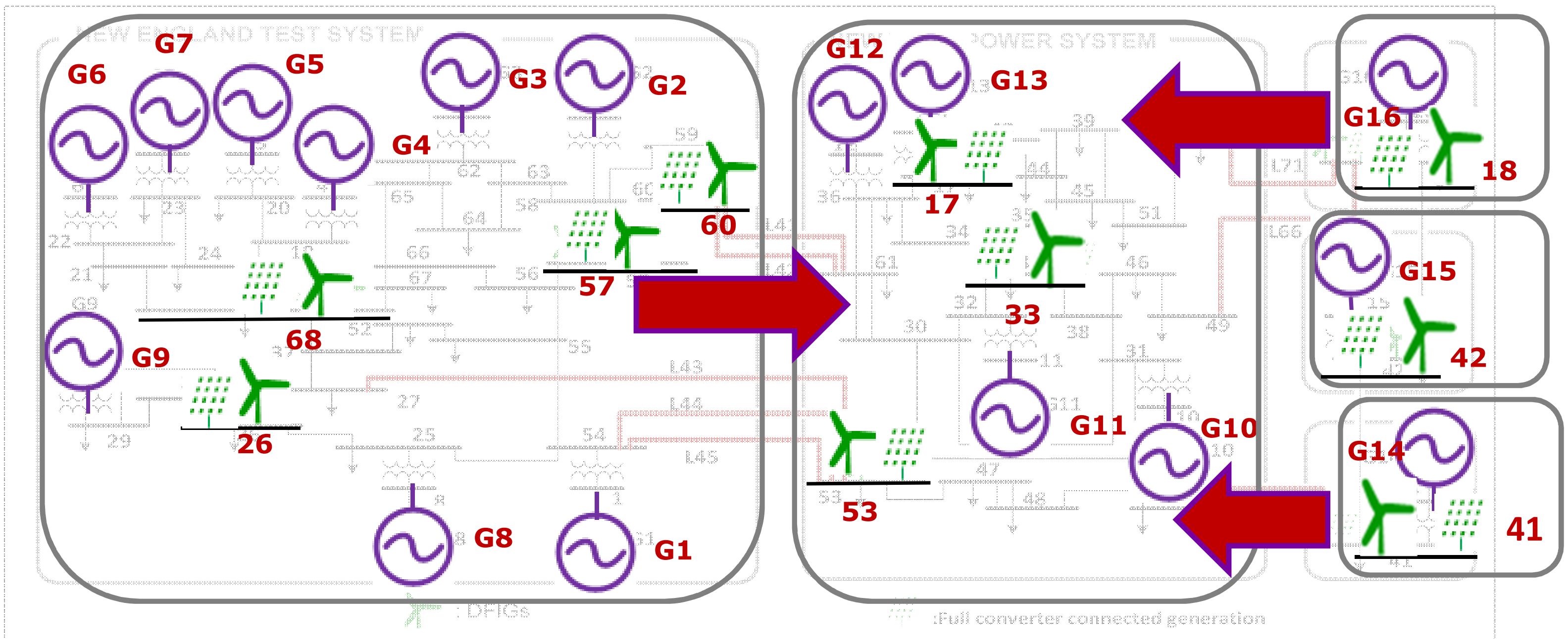
NYPS is importing from surrounding areas (NETS and Equivalent Area) due to generation shortfall of approximately 2.7GW.

Test System with Renewables



Wind turbines are modelled as Type 3 doubly fed induction generators (DFIGs). Full converter connected generation (wind & PV) is modelled as Type 4 WTG. The RES generation is placed to minimise the effect on original power flows and voltage profile in the network.

Test System with Renewables



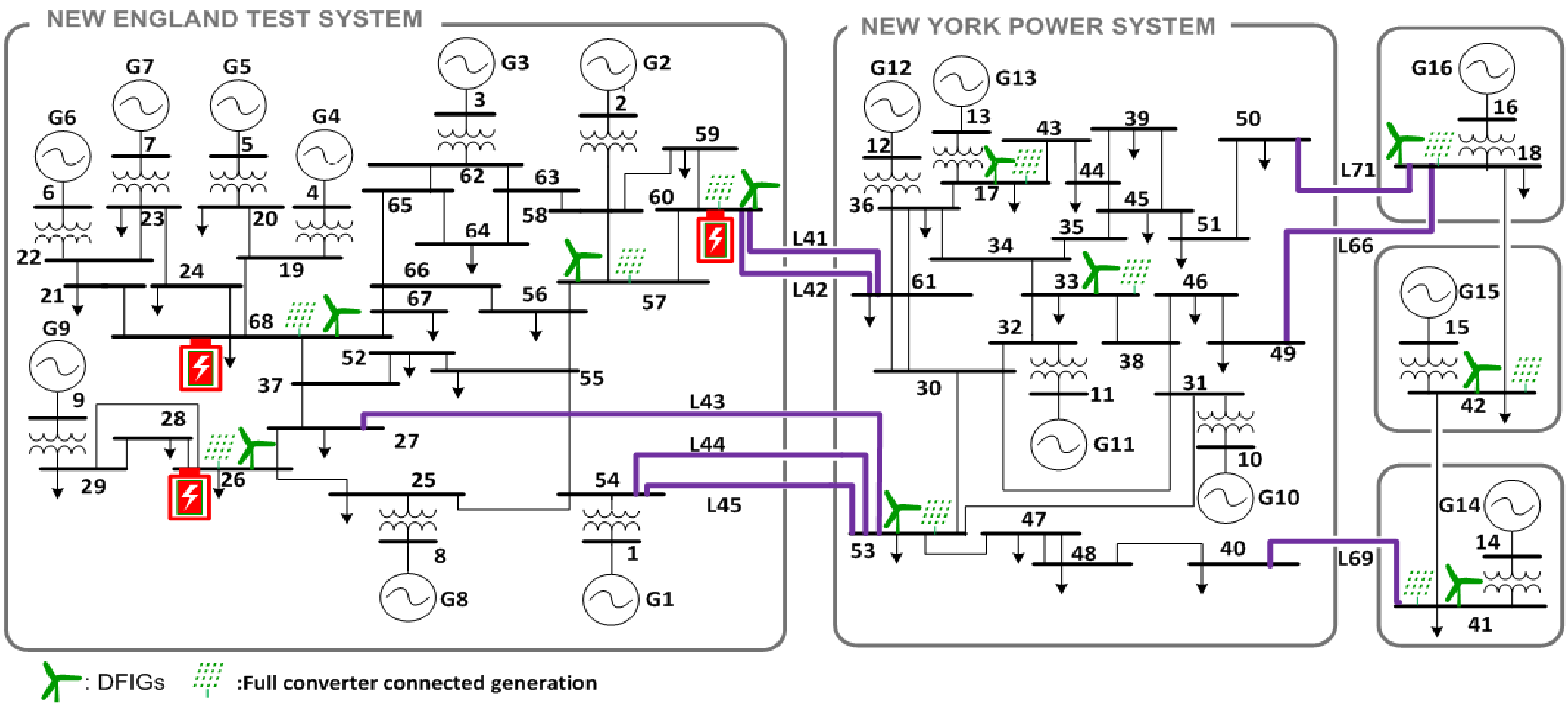
Test System with Renewables

Large scale bulk ESS

One large scale ESS is installed at bus 60 (selected based on bus fault level, transmission lines capacities and proximity to RES)

Test System with Renewables

Distributed ESS



Three - ESS are installed at bus 60, 68 and 26 (selected based on transmission lines capacities and proximity to RES)

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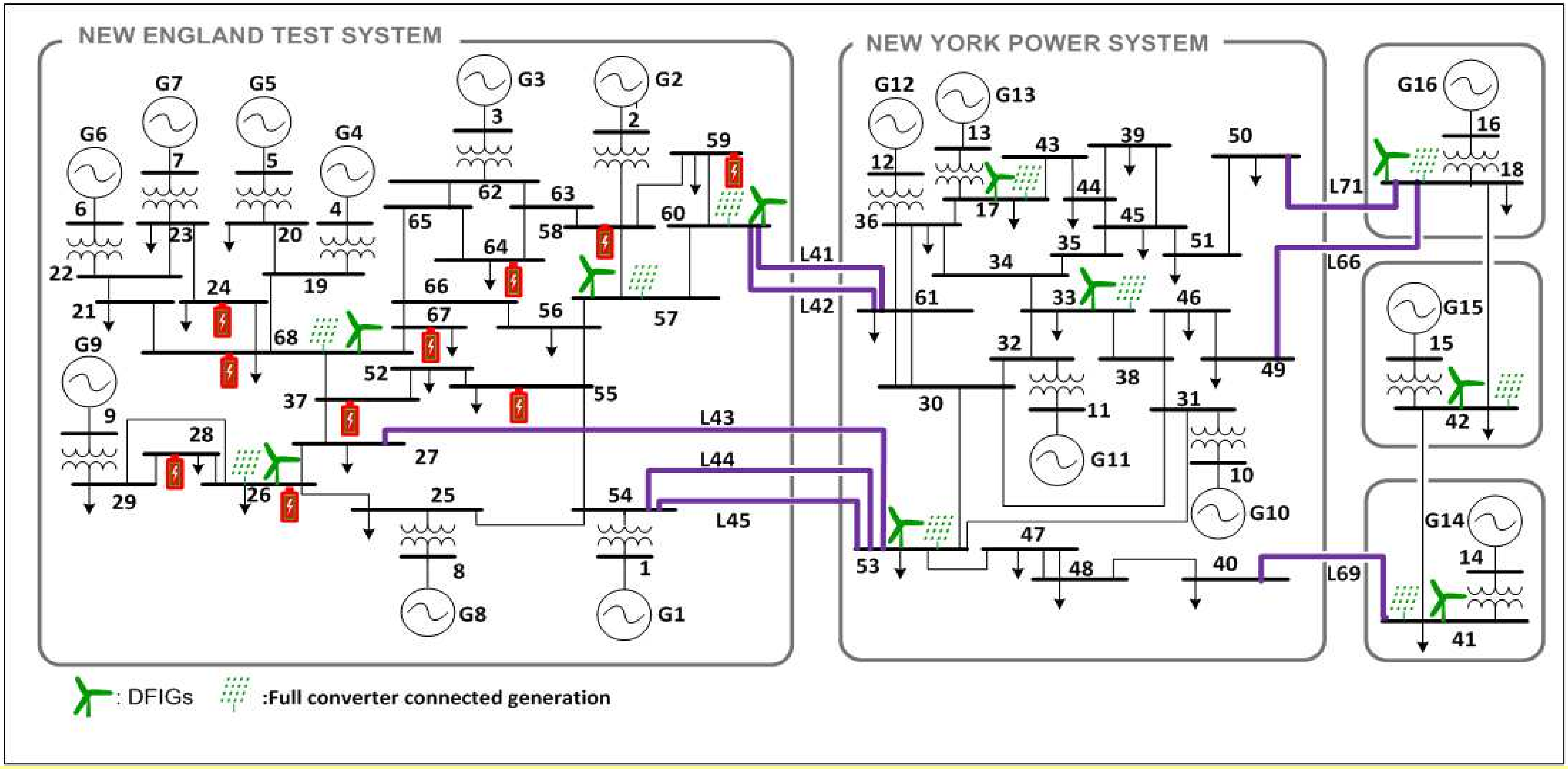
Test System with Renewables

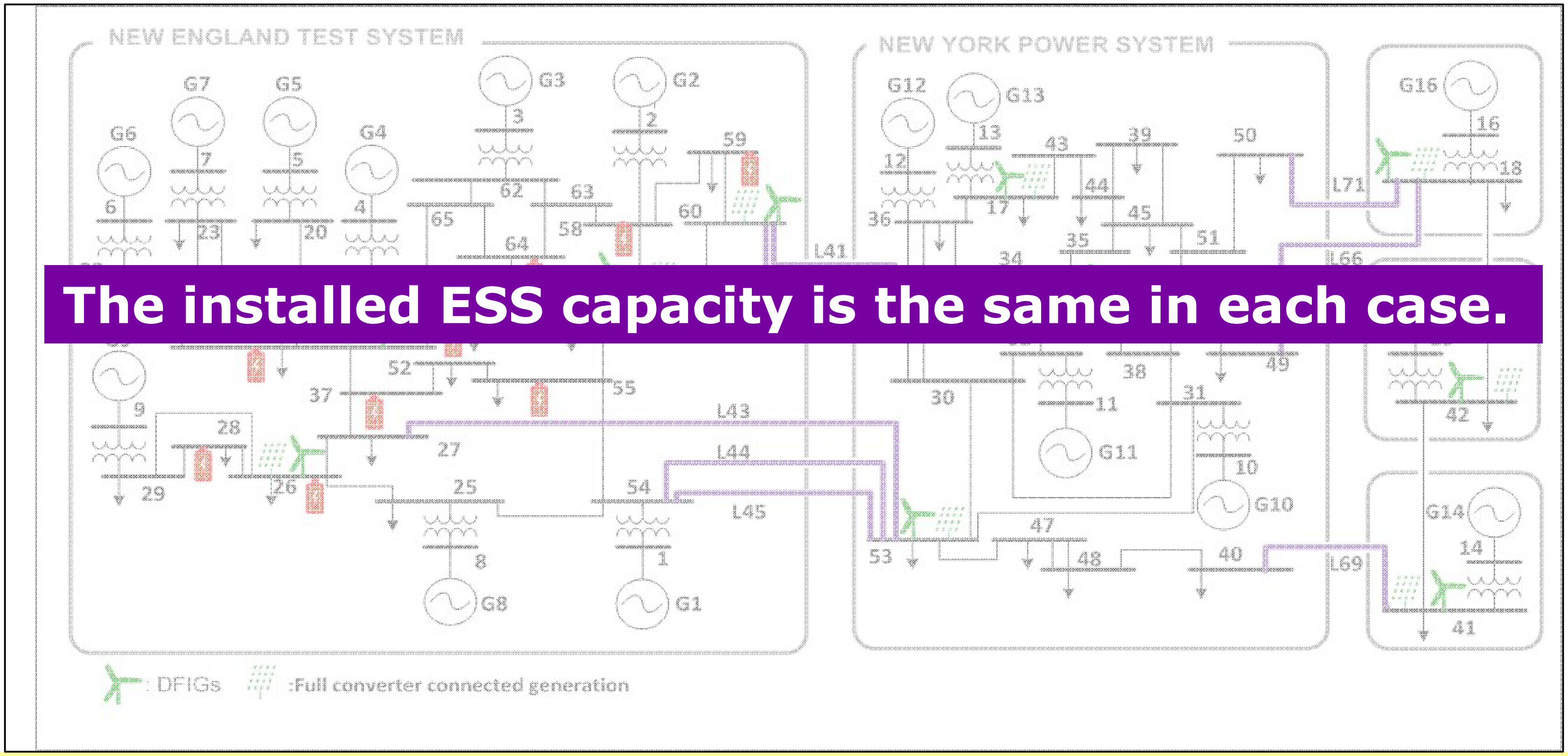
Distributed ESS



Ten - ESS are installed at bus 21, 24, 26, 28,37,55,58,59,64 and 67

Test System with Renewables

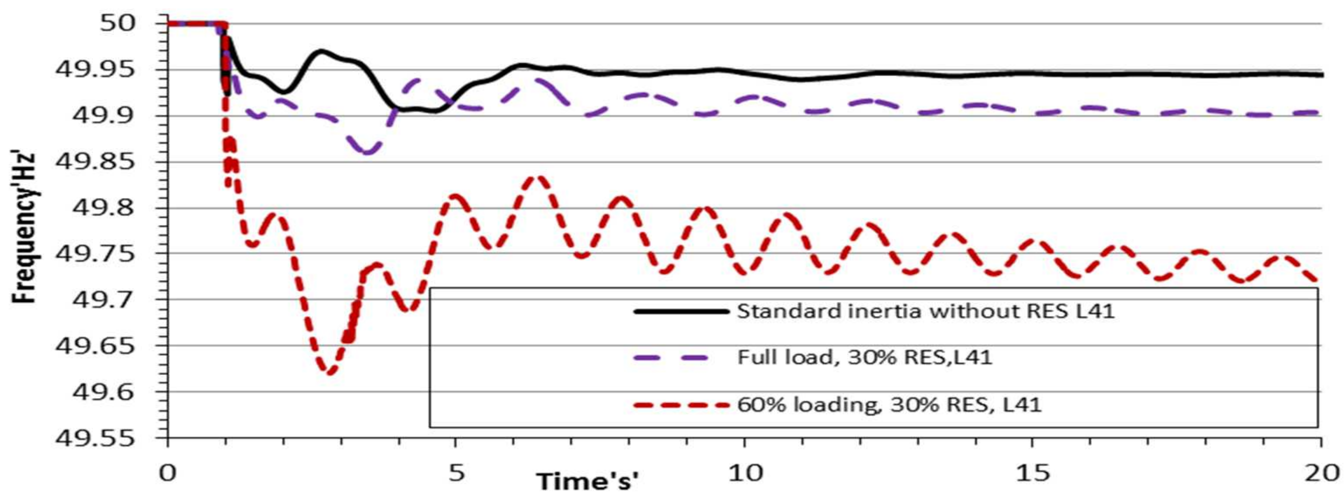
Distributed ESS



The installed ESS capacity is the same in each case.

Ten - ESS are installed at bus 21, 24, 26, 28,37,55,58,59,64 and 67

Effect of reduction in inertia on frequency nadir and ROCOF

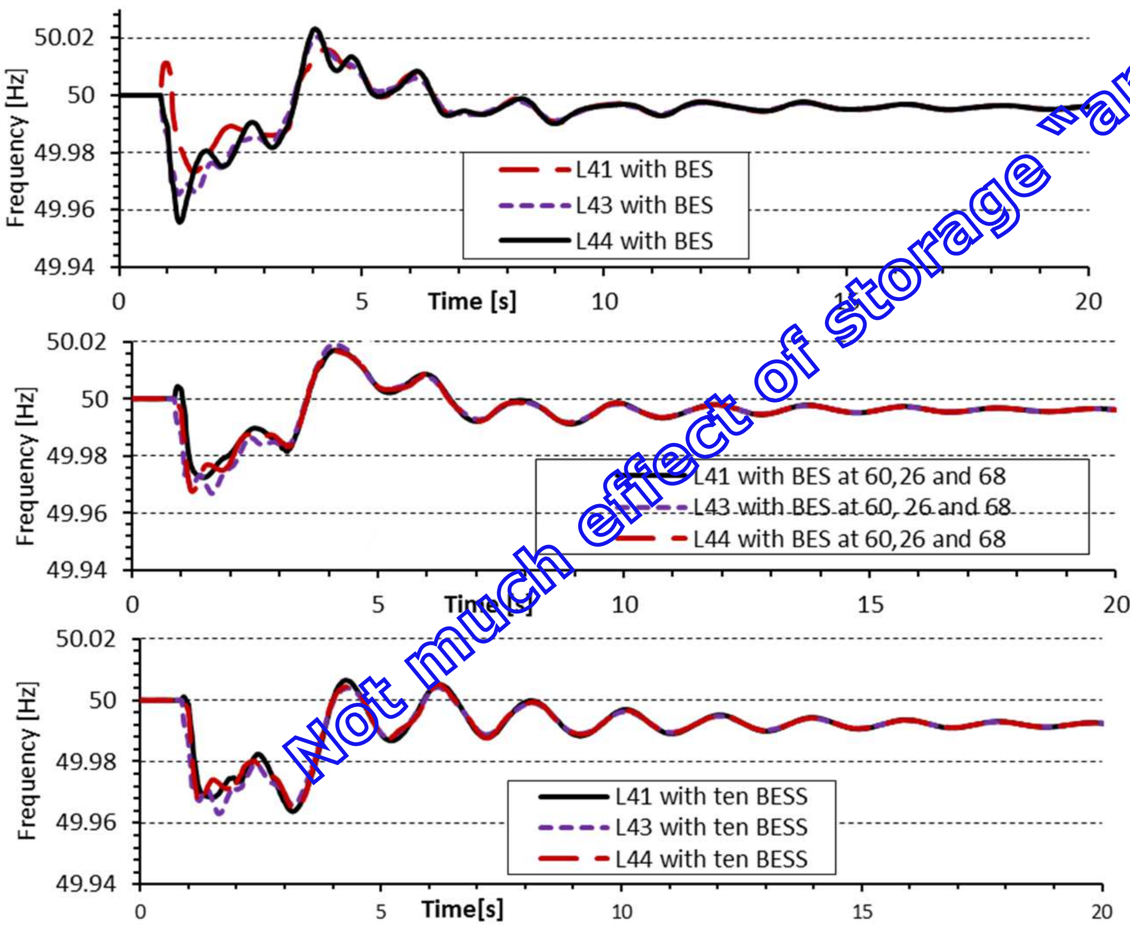


	Frequency nadir [Hz]	ROCOF [Hz/s]	Time of frequency nadir occurrence
No RES	49.9	0.029	4.5
30% RES	49.86	0.063	3.4
55% RES	49.62	0.22	2.7

Comparison of centralized and distributed ESS arrangements

Nominal loading, 30% RES , H_{sys} = 6.4 s

Not much effect of storage "arrangement"



The contribution to frequency response (improvement in frequency) due to BESS is different (slightly) at each bus connected to NYPS.

Frequency nadir following an active power disturbance is nearly the same at each bus connected to tie-lines to NYPS as number of ESS increases from 1 to 3.

Frequency nadir stays the same on each bus connected to tie-lines to NYPS as number of ESS increases from 3 to 10.

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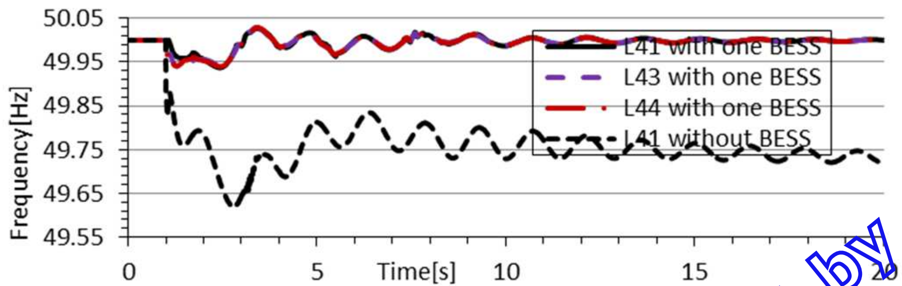
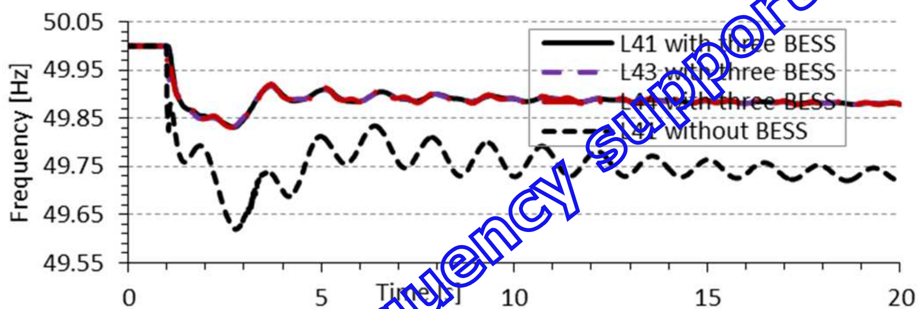
Comparison of centralized and distributed ESS arrangements

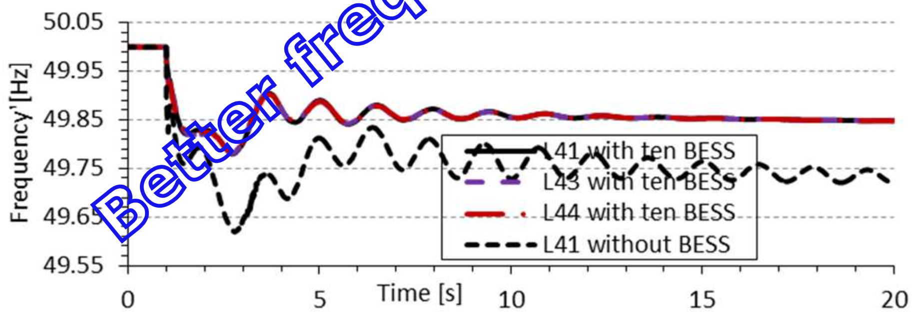
60% loading, 55 % penetration of RES, H_{sys} = 5.26 s



Frequency nadir is improved from **49. 62 Hz** to **49.94 Hz** with 1 large ESS



Frequency nadir is improved from **49.62 Hz** to **49.83 Hz** when the number of ESS increases to 3.



Frequency nadir is improved from **49.62 Hz** to **49.73 Hz** when the number of ESS increases to 10.

Better frequency support by centralised storage

Effect of location of ESS on frequency nadir

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Effect of Reduction in Inertia

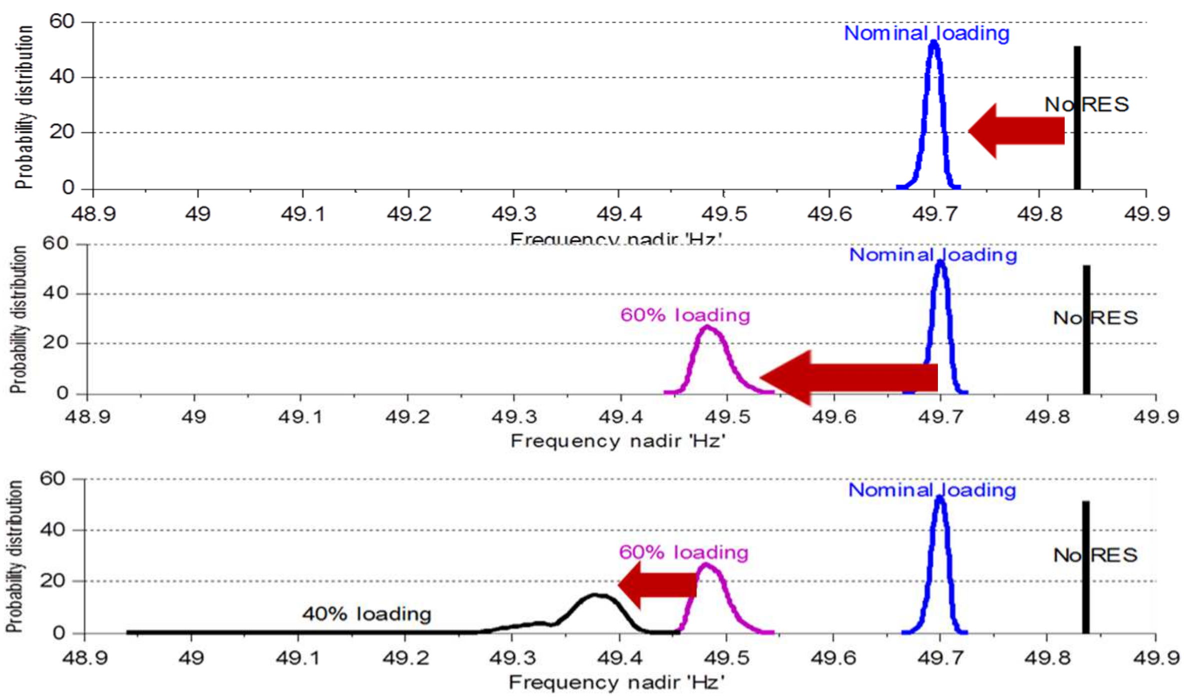
No RES in the network **System inertia:** 7.95

30% RES in the network **System inertia: 6.83 s (14%)**

46% RES in the network **System inertia: 4.14 s (48%)**

52% RES in the network **System inertia: 2.83 s (64%)**

Active power disturbance: simultaneous outage of G2, G7 and G10



Frequency nadir drops from 49.84 Hz to 49.7 Hz (0.14 Hz)

Most probable value drops from 49.7 Hz to 49.47 Hz (0.23 Hz)

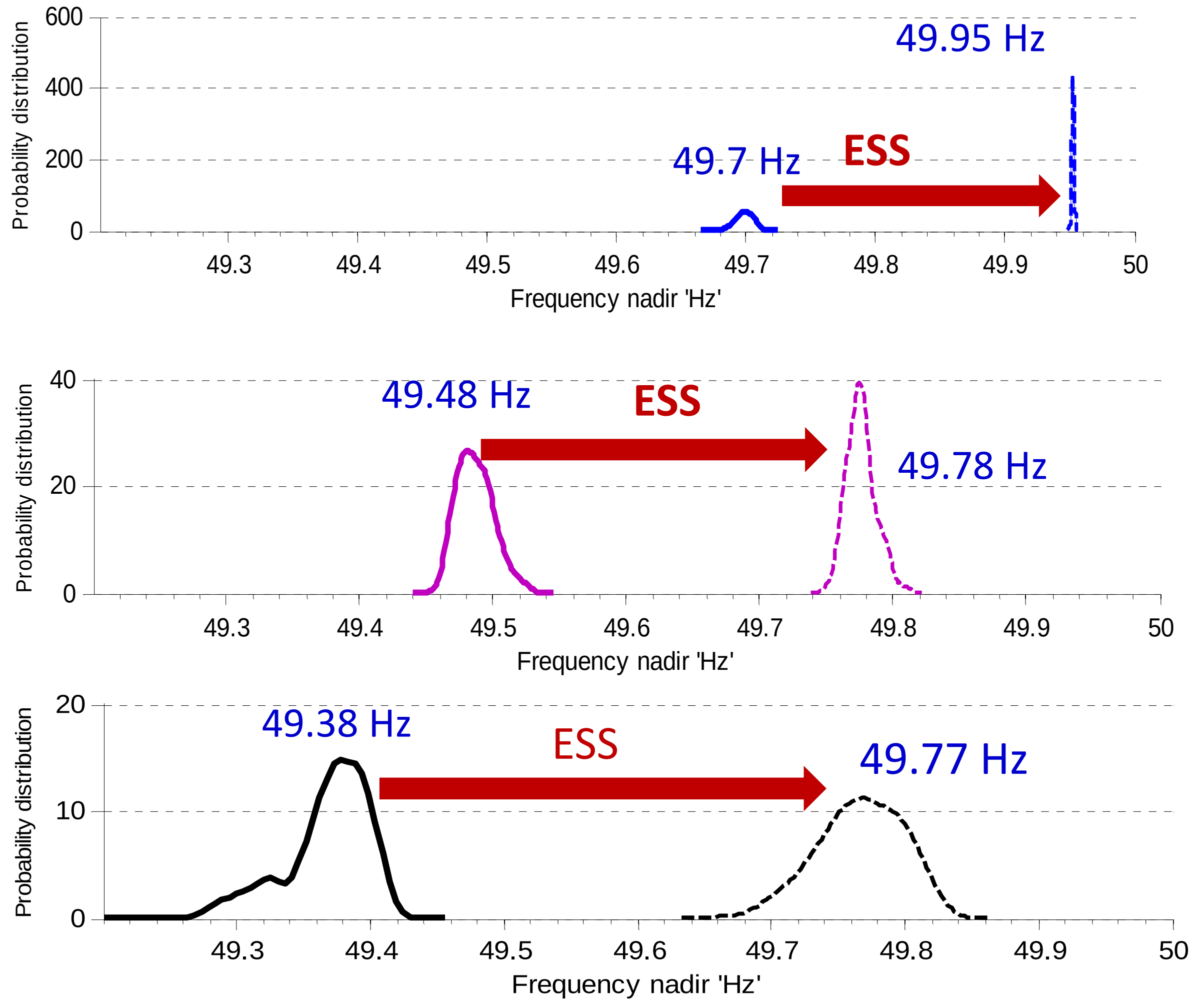
Most probable value drops from 49.48 Hz to 49.38 (0.1 Hz)

Effect of location of ESS on frequency nadir

30% RES
Nominal loading

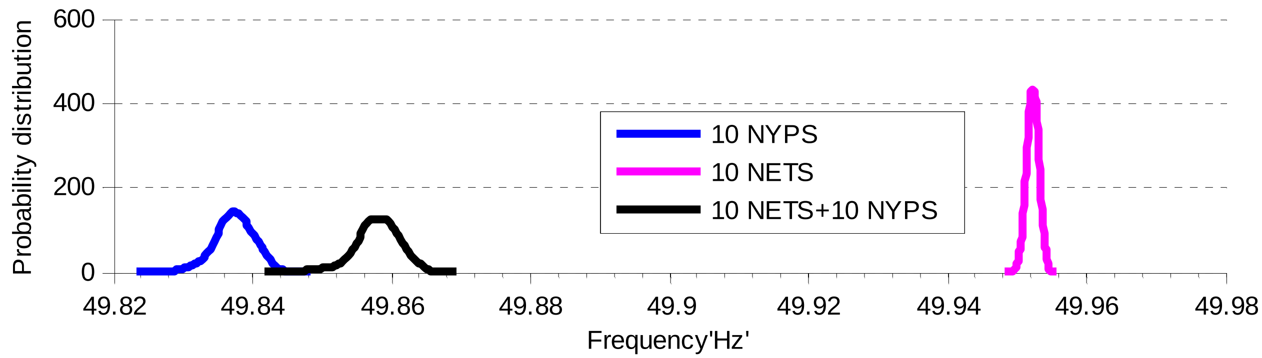
46% RES
60% loading

52% RES
40% loading



Effect of location of ESS on frequency nadir

30% RES
Nominal loading



46% RES
60% loading

52% RES
40% loading

Effect of location of ESS on frequency nadir

30% RES
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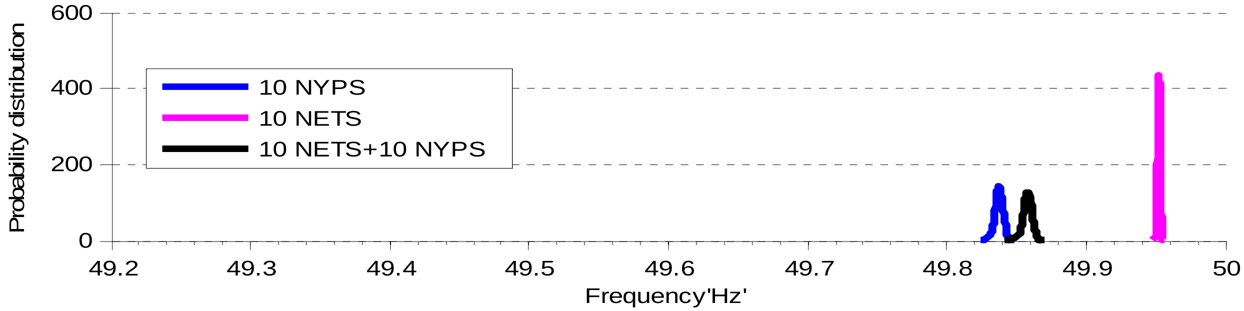
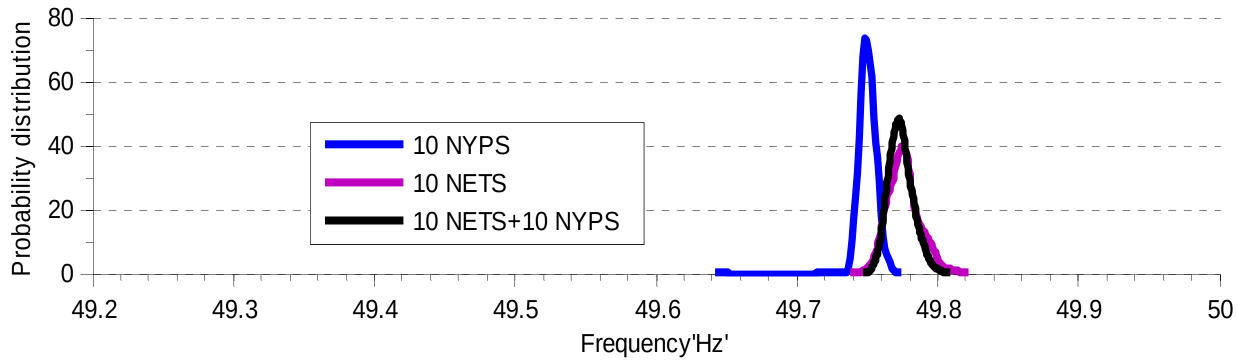


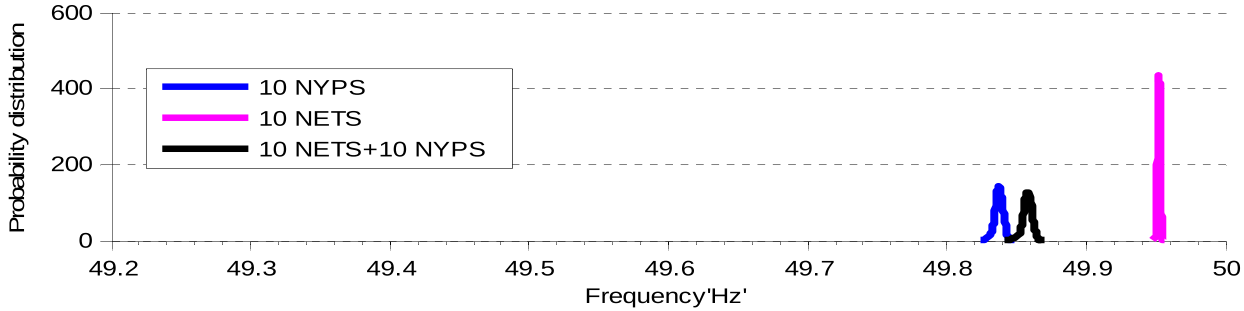
46% RES
60% loading



52% RES
40% loading

Effect of location of ESS on frequency nadir

30% RES
Nominal loading



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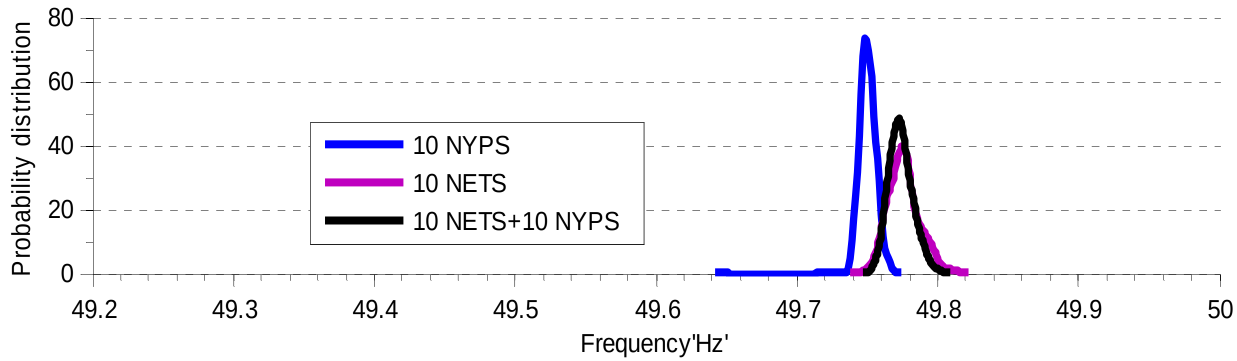

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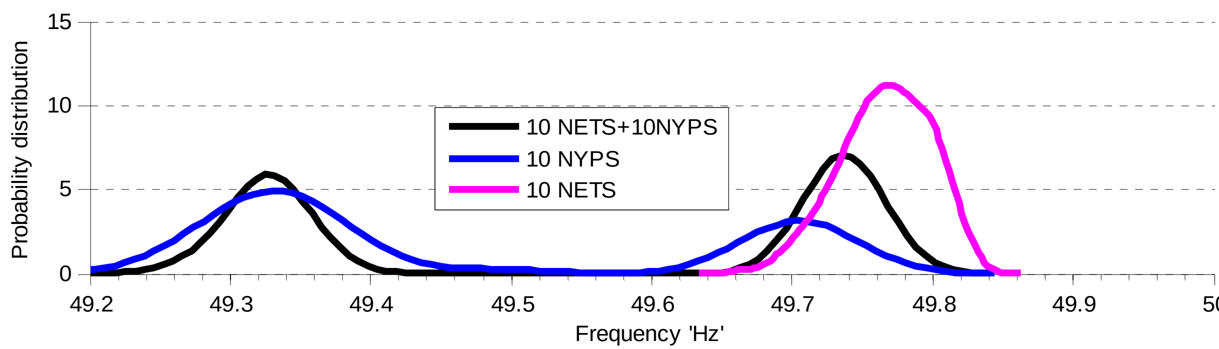
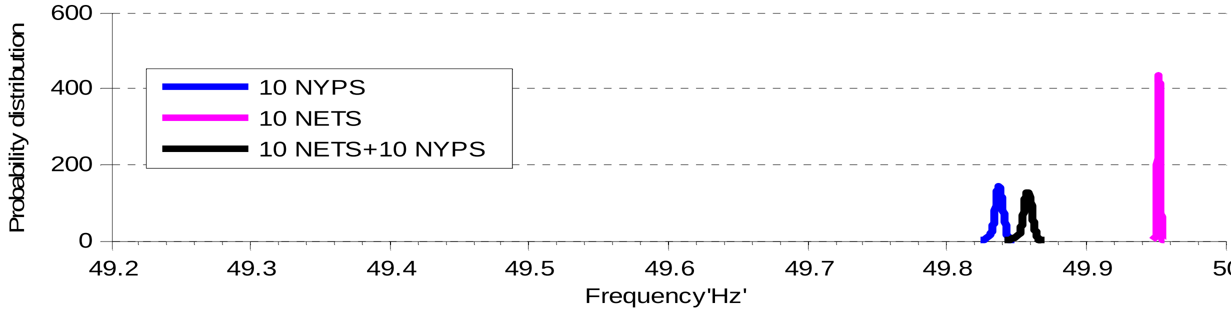


Effect of location of ESS on frequency nadir

30% RES
Nominal loading



46% RES
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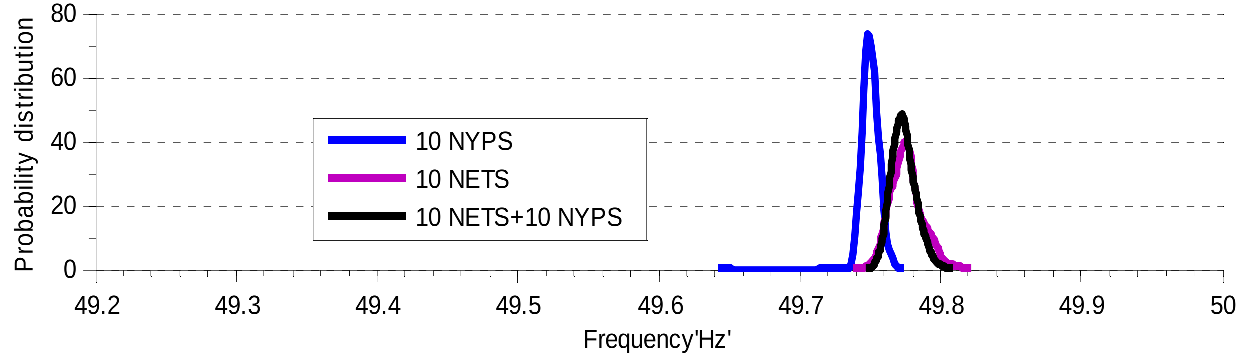
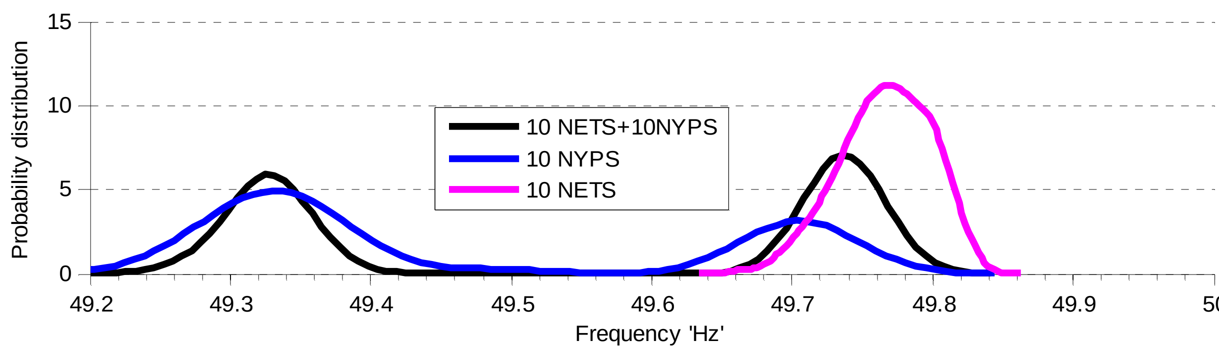
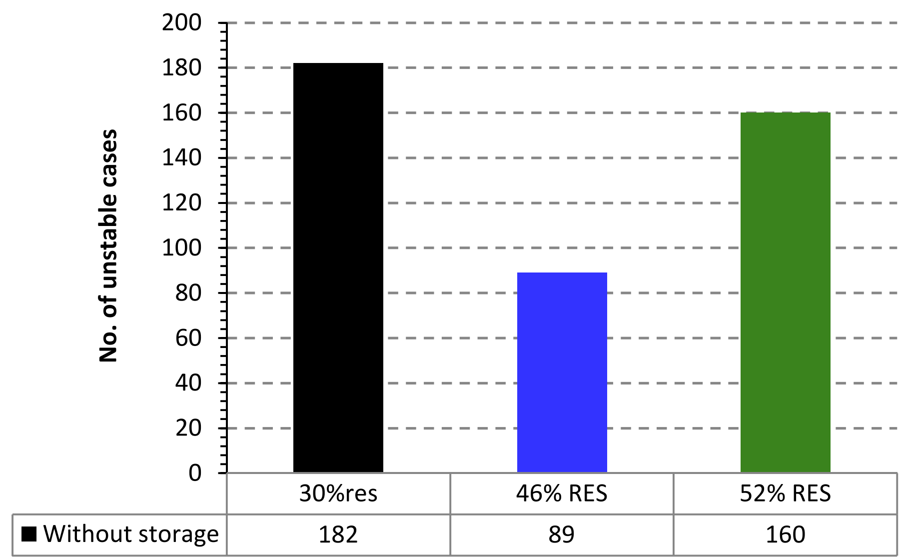


52% RES
40% loading



Effect of ESS on transient stability

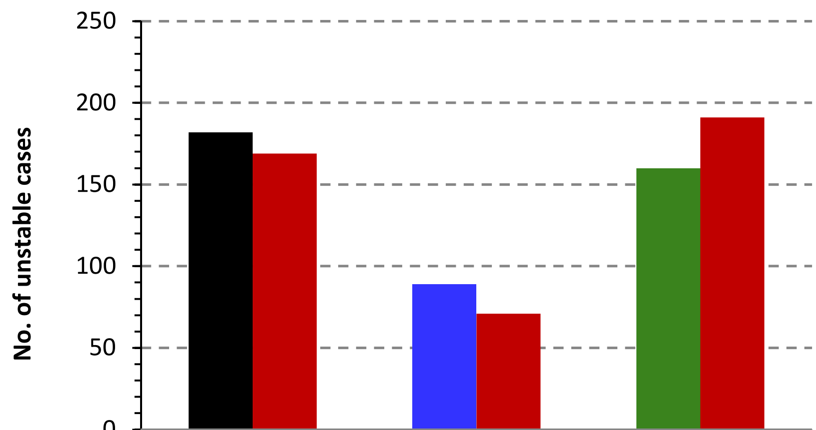
Assessing Transient Stability of the System



46% RES, the effect of de-loading the generators is more significant , compared to the reduction in the inertia in the system.

However, when inertia is further reduced (52% RES), this effect becomes more significant.

Assessing transient stability of the system



	30%res	46% RES	52% RES
Without storage	182	89	160
With storage	169	71	191

-7% **-20%** **+19%**

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Summary

- The mode of deployment of ESS can considerably affect the level of support ESS provides to system frequency when the proportion of RES becomes high.
- Similarly, the location of ESS can play a significant role in improving frequency stability of low inertia power system.

- The ESS installed for primary frequency control can improve transient stability of the system. However, the same control increases the number of unstable cases when the proportion of RES becomes significant.