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The Role and Need For Inertia in a NEM-Like System

Summary

The Role and Need For Inertia in a NEM-Like System

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Abbreviations

AAS	Automatic Access Standard
AEMC	Australian Energy Market Commission
AEMO	Australian Energy Market Operator
BOP	Balance of Plant
CUO	Continuous uninterrupted operation
EMT	ElectroMagnetic Transient
FFR	Fast Frequency Response
GFL	Grid FolLowing plant
GFM	Grid ForMing plant
GPS	Generator Performance Standards
HVRT	High Voltage Ride Through
IBR	Inverter Based Resource
LVRT	Low Voltage Ride Through
NEM	National Electricity Market
NER	National Electricity Rules
OLTC	On Load Tap Changer
OOS	Out of Service
OPDMS	Operation Planning and Data Management System
PFR	Primary Frequency Response
POC	Point of Connection
PPC	Power Plant Controller
RMS	Root Mean Square
RoCoF	Rate of Change of Frequency
SCR	Short Circuit Ratio
THD	Total Harmonic Distortion

Executive Summary

The Australian Energy Market Operator ('AEMO', the client) operates the NEM power system to be resilient, remain synchronised and operate with a stable AC frequency through large disturbances such as generator trips, load rejection and separation events. Traditionally this was ensured through reliance on the mechanical inertia of large rotating machines to arrest, limit and regulate sudden deviations in frequency.

Technically, 'inertia' denotes an automatic nexus between movements in a device's active power level and movements in the grid frequency in an AC power system. This nexus operates in both directions providing feedbacks that, in properly configured systems, ensure predictable and 'stabilisable' behaviour down to the very short timescales where explicit, programmed closed-loop controls cannot be relied upon. It may be provided through inherent electromagnetic effects in rotating machines ('synchronous inertia') or through explicit fast-acting controls in inverter-based plants ('synthetic inertial response').

As the system transitions to lower levels of synchronous inertia, there is a high likelihood that aggregate inverter-based responses will be increasingly used to manage frequency and displace some need for synchronous inertia. This could allow the NEM to reach ultra-low synchronous inertia levels under system normal conditions. But given the focus around inertia requirements has largely been on frequency control to date, AEMO is concerned that such ultra-low inertia levels could result in adverse system stability outcomes beyond frequency, particularly if the remaining synchronous inertia on the power system is geographically scattered in a way likely to give rise to regional shortfalls in stability margins.

The reported study is intended to support AEMO investigations on the necessity of a long-term lower boundary for the total amount, and distribution of synchronous inertia on the mainland NEM under system intact conditions. It aims to do so by providing high-level analysis of frequency and angle stability in a system having similar characteristics to the NEM, to understand in particular:

(a) The extent to which the geographic distribution of synchronous inertia across the power system impacts various stability phenomena in the power system as the total level of synchronous inertia on the power system varies.

(b) Whether the power system could run entirely at zero or very low levels of synchronous inertia.

(c) At what level of synchronous inertia would AEMO need to consider other power system stability phenomena in the calculation of inertia requirements.

To keep the supporting evidence at a tractable level, analysis was based on time-domain simulations in PSS/E software, using a significantly simplified network model that retains key aspects of the NEM (including geographic spread, 'thin' interconnectors, and regions of differing strength) while avoiding the high complexity that impedes engineering intuition. At the level of detail being considered, the RMS framework provided by PSS/E was considered sufficient to represent salient features of interest, including comparative trajectories of frequency, RoCoF and active power flows in response to large disturbances. The base case for studies was based on a plausible 2031 operating scenario derived from AEMO's Integrated System Plan. Generic models by Vysus Group were used to represent the controls in grid-following and grid-forming plants at high level.

It should be stressed the studies undertaken are of a speculative and high level nature, and the modelling representative of NEM behaviour in only the broadest terms. A great detail more analysis will be required, considering a much broader set of operating conditions and contingencies in full detail (a necessarily much more time-consuming exercise) before real-world operation of the power system could be considered under the conditions modelled here. The present studies do highlight the value of this further analysis and suggest some promising directions for more investigation in the near term.

Thus, while the study findings documented in this report should not be read as fully definitive in the context of the NEM without further analysis, they do point to the following broad conclusions.

Geographic distribution of synchronous inertia

The locational distribution of synchronous inertia in the NEM is contingent on its history, with each NEM region starting out as self-sufficient, and interconnectors developed initially for trading of surplus capacity at the margin. The operation of the NEM as a single market since the 1990s has weakened the role of autonomous regional operations but synchronous inertia sources still retain a strong regional identity.

Study evidence indicates that the NEM continues to draw substantial benefit from this historical situation, our general conclusion being that 'location matters'. That is, the geographic concentration or spread of synchronous inertia sources has material consequences for regional and global stability of the system. This is the case not only for post-contingent operation but also for intact 'system normal' operation. While results mostly confirmed the intuitively expected inverse relationship between cumulative inertia and large-disturbance performance metrics such as maximum RoCoF and peak frequency deviation, notable exceptions were identified with many attributable to locational factors.

The results for 500MW generator rejection events in the VIC region, in particular, suggest it is unlikely to be technically feasible to concentrate synchronous inertia in a single region (QLD in this case) in the expectation that all regions will benefit from the concentrated inertia source. While the fact that frequency is a system-wide characteristic may intuitively suggest a single location-agnostic 'inertia market' is workable, stability in practice is about much more than sharing a frequency variable with other parts of a system.

The results for 600MW generator rejection events in the QLD region further suggest that a concentration of synchronous inertia in one region may not even be optimal when considering stability in that region alone. Overall, the examples provided show that systems with overly concentrated synchronous inertia can have inferior stability performance relative to those with a broader geographic distribution even when the latter have a lower level of inertia overall.

Low to zero levels of synchronous inertia

The results at this restricted level of modelling indicate it is feasible at a high level to operate the power system with low to zero levels of synchronous inertia if there is a basic level of synthetic inertial response available from grid-forming IBRs. While it was not the purpose of this study to investigate the minimum required size or location of GFM plants or to optimally tune these plants, it has been found that a system with 37,000MVA.s of synthetic inertial response (in round figures) obtained from 10,500MVA of grid-forming IBR capacity was able to operate in a stable manner in the absence of synchronous machines, and withstand a limited range of disturbances without an exhaustive tuning effort.

The study results also indicate a system with zero synchronous inertia may behave in a manner qualitatively different even from one with small but nonzero synchronous inertia, and further investigations on such systems are warranted to understand this behaviour. Thus it is not unlikely that to the extent the zero-machine cases presented here display inferior performance, this could be improved to some degree through more detailed study and control tuning. It remains likely that in the real NEM, a minimum floor level of rotating synchronous inertia will persevere for the foreseeable future.

Studies also reveal a dramatic difference in stability performance between cases with low synchronous inertia supported by a moderate level of synthetic inertial response, and those without such support. In future scenarios with high penetrations of IBRs displacing synchronous machines it may be presumed that at least a small proportion of these will utilise GFM technology; indeed in the NEM this is all but guaranteed under recent rule changes to address system strength. While this should not be interpreted as a target, our results here indicate that a level of GFM plant corresponding to at least 10% of installed IBR generation capacity (where this may be provided either by BESS or generation plant) is sufficient to achieve material system benefits.

In any event, further work will be needed to study in detail the feasibility of operating the real NEM at low to zero levels of inertia and the minimum level of GFM or other technology likely to be needed.

Interaction with other stability phenomena

Inertia characteristics in AC power systems, as defined in this report, are known to have a close technical relationship with system strength characteristics (broadly defined as those system characteristics that govern the level of short-circuit fault current and the sensitivity of local voltage magnitudes to disturbances in power flow). While it was not the purpose here to study this relationship, it is indirectly apparent where certain study cases did not display stable behaviour at all for certain disturbances. A common reason for this on further investigation was failure of voltage stability leading to generating units tripping on over- or under-voltage in a cascading sequence.

Under the assumptions in these studies (including an assumed minimum level of grid-forming plant amongst the rollout of IBRs) the level of synchronous inertia in the base 'Case 3' scenario, consistent with the Integrated System Plan 'step change' scenario for 2031, was generally robust to these other stability effects. However, it is apparent that any further reduction in synchronous inertia, or changes in assumptions on the distribution of synchronous inertia, can render the system vulnerable to other types of instability in the absence of remedial measures such as additional voltage support, or a higher penetration of grid-forming IBRs. It therefore appears likely that AEMO will need to give closer consideration to the interaction of inertia with other stability characteristics under plausible post-2030 operating conditions for the NEM.

1. Background and Scope: Defining 'Inertia' in a Large AC System

1.1. Project Background

The Australian Energy Market Operator ('AEMO', the client) is responsible for the secure operation of the National Electricity Market (NEM) power system. A key aspect of system security is resilience to large disturbances such as generator trips, load rejection and separation events, and the ability to remain synchronised and operate with a stable AC frequency. Traditionally this was ensured through reliance on the mechanical inertia of large rotating machines to arrest, limit and regulate sudden deviations in frequency resulting from large disturbances.

AEMO published in March 2023 an 'Inertia in the NEM Explained' discussion paper [1] summarising the inertia characteristics of AC power systems and the challenge posed by reduction in synchronous inertia due to the retirement of large thermal power stations.

As the system transitions to lower levels of synchronous inertia, there is a high likelihood that aggregate inverter-based responses (either fast frequency response or synthetic inertial response) will be increasingly used to manage frequency and displace some need for synchronous inertia. The latest Frequency Operating Standard has instated a maximum Rate of Change of Frequency (RoCoF) of +/-1Hz/s over any 500ms window for the mainland NEM. This in theory allows for the utilisation of control systems to meet the requirement and therefore reduce minimum synchronous inertia requirements. This could allow the NEM to reach ultra-low synchronous inertia levels under system normal conditions.

Given the focus around inertia requirements has largely been on frequency control to date, AEMO is concerned that permitting the NEM to reach ultra-low inertia levels could result in adverse system stability outcomes beyond frequency, particularly if the remaining synchronous inertia on the power system is geographically dispersed.

AEMO accordingly wishes to have frequency control modelling and studies undertaken to provide an evidence base to capture the potential stability concerns that could arise in the NEM under ultra-low synchronous inertia conditions. This evidence will be used to supplement and expand on AEMO's document [1].

1.2. Purpose

The reported study is intended to support AEMO's objective to assure secure operation of the power system, and specifically to ensure adequate capacity for frequency control is available while managing the risk of potential system instability.

To achieve this objective, advice is sought on the necessity of a long-term lower boundary for the total amount, and distribution of synchronous inertia on the mainland NEM under system intact conditions, that is informed by high-level analysis of frequency and angle stability in a system having similar characteristics to the NEM. At a high level, AEMO seeks to understand:

(a) The extent to which the geographic distribution of synchronous inertia across the power system impacts various stability phenomena in the power system as the total level of synchronous inertia on the power system varies.

(b) Whether the power system could run entirely at zero or very low levels of synchronous inertia.

(c) At what level of synchronous inertia would AEMO need to consider other power system stability phenomena in the calculation of inertia requirements.

To keep the supporting evidence at a tractable level, analysis is based on a significantly simplified network model that retains key aspects of the NEM (including geographic spread, 'thin' interconnectors, and regions of differing strength) while avoiding the high complexity that impedes engineering intuition. The simplified system model is detailed in Section 2 of this report.

The study work also draws on the prior experience of Vysus Group in power system modelling, plant performance assessment, and wide-area integration of new energy technologies with management of associated stability issues.

1.3. Inertia: Background and Definitions

AEMO's paper [1] provides the following working definition of inertia:

> *An* inertial response *is the immediate, inherent, electrical power exchange from a device on the power system in response to a frequency disturbance.* Power system inertia *is the aggregate equivalent inertia of all devices on the power system capable of providing an inertial response.*

Understood this way, 'inertia' denotes an automatic nexus between movements in a device's active power level and movements in the grid frequency in an AC power system. This nexus operates in both directions providing feedbacks that, in properly configured systems, ensure predictable and 'stabilisable' behaviour down to the very short timescales where explicit, programmed closed-loop controls cannot be relied upon.

AEMO's paper further distinguishes between *synchronous inertia*, where the power-frequency nexus is a property of the physics of a rotating machine, and *synthetic inertial response*, where it is a property of low-level controls acting on sufficiently fast time scales.

Frequency to Power: Inertial Response

Inertial response might also be termed *synchronising power*: a device 'observes' the power system going 'out of synchronism' as its frequency rises or falls, and immediately responds with a change in power supplied or drawn, the direction of the change being that which will tend to restore the frequency to its nominal level (as discussed further below).

Importantly, whether it is being provided by a synchronous machine or a grid-forming IBR, the inertial response arises directly from two key electrical properties of the device:

1. appearing to the electrical network as a Thévenin voltage source behind a transient reactance *X*'; and
2. holding the phase displacement of its internal source voltage nearly constant over short time scales.

For a synchronous machine these are fundamental electromagnetic properties. Meanwhile, for an electronic converter of 'grid-forming' type, (1) follows from the device construction as a switched voltage source with AC-side series filtering reactance *X*', while (2) is established by pulsewidth modulation of the source voltage with a slow moving angle parameter. The latter is the key property that distinguishes grid-forming converters from the grid-following variety, where the source angle is made to track the grid voltage angle as identified by a PLL.

Together, (1) and (2) establish the fundamental power exchange law

$$P = \frac{|E_a||V_t|}{X'} \sin(\delta_a - \delta_t)$$

where $|E_a|$ and $|V_t|$ are respectively the internal source and grid terminal voltage amplitudes, and δ_a and δ_t the corresponding phase angle displacements. Any movement in external grid frequency is perceived in the first instance as an advance or retardation in the angle δ_t, which triggers an immediate active power response governed by this law.

It may be observed that there is no 'inertia' parameter governing this behaviour, which is a consequence of basic properties of AC circuits. Rather it is the effective transient reactance *X*' that primarily determines the size of the response. However, 'closing the loop' on the power system dynamics requires describing how disturbances in active power *P* influence the system frequency itself, and this is an explicit function of inertia parameters.

Power to Frequency: Inertial Regulation

It is a commonplace assertion that in AC power systems, any imbalance between power supplied and power demanded will quickly lead to a movement in system frequency – rising frequency for an excess of supply over demand and falling frequency for an excess of demand over supply. The underlying mechanism for this is found in electric circuit laws, in combination with plant dynamics governed by inertia.

A power exchange law like the above is satisfied for every branch in an AC network. Because network branches have non-negligible resistance *R* in addition to reactance *X*, the form of this law is only slightly more complicated:

$$P - \frac{R}{X}Q = \frac{|V_1||V_2|}{X}\sin(\delta_1 - \delta_2)$$

where $|V_1|$, $|V_2|$ are voltage magnitudes at the branch endpoints and δ_1, δ_2 the corresponding phase displacements. The law ensures that under stable power flow conditions in the network, disturbances in phase angles will propagate rapidly across the network, with relativities that may change where there are localised changes in power flow *P*. The existence of network resistances means that reactive power flows *Q* also play a role, albeit a secondary one.

(When considering very short-term dynamics it is also important to keep in mind the above law is strictly valid only after decay of transmission line and other network transients, which may persist up to a few milliseconds after a disturbance.)

The crucial role of inertia here is to regulate the ultimate movement in phase angles δ. At a synchronous machine, a direct coupling exists between the voltage angle δ_a and the physical rotor displacement (relative to a 50Hz synchronous rotation) by virtue of Faraday's law, and the rotor displacement obeys the (approximate) swing equation

$$\frac{1}{\omega_0}\frac{d^2\delta_a}{dt^2} = \frac{1}{2H}(P_m - P_e)$$

where P_e is the power exchanged with the network, P_m the prime mover input power (almost constant on short time scales) and *H* the inertia constant as in [1]. Due to the close coupling of phase angles across the system, the true angle dynamics are the joint outcome of swing equations for each synchronous machine (as well as each grid-forming IBR whose source angle dynamics are programmed to behave in a similar manner). To a first approximation, the system behaves as a single rotating mass whose inertia constant H_{tot} is the weighted sum of individual *H* constants (weighted by the size in MVA of each plant).

If the movement in phase angles persists, the quantity $\omega_a = (1/\omega_0)\, d\delta_a/dt$ represents the per-unit electrical frequency deviation from nominal (and the physical rotor speed deviation for a synchronous machine). Writing the swing equation in the equivalent form

$$\frac{d\omega_a}{dt} = \frac{1}{2H}(P_m - P_e)$$

makes explicit the linkage between the excess or deficit of exchanged power P_e on the one hand, and the rate of change of frequency (RoCoF) on the other, directly mediated by the inertia constant *H*. In this way, every plant that presents an AC voltage source to the network plays a role in regulating the movement in angles and frequency across the system.

Viewed at a whole system level in aggregate, it follows that in a system with high inertia H_{tot}, frequency disturbances will be arrested more easily, with a lower RoCoF and smaller deviation in frequency from its nominal level before the programmed primary frequency response (PFR) intervenes. Conversely, in a system with low inertia, the disturbance will result in a higher RoCoF and a larger peak deviation from nominal frequency prior to the same PFR intervention.

So in summary:

- inertial *response* describes how frequency or phase displacements in the power system translate automatically into movements in power exchange *P* (with magnitude governed by an internal transient reactance *X*');
- inertial *regulation* describes how excesses or deficits in power exchange both at a local device and at a global system level automatically feed back into movements in phase angles and electrical frequency (with rate of change governed by inertia constants *H*).

Both are complementary aspects of what is commonly referred to as 'inertia'. As such they combine to govern the *short term* response to disturbances in frequency and power exchange, with other (more explicit) frequency controls managing the response in the longer term.

Synthetic Inertial Response and Fast Frequency Response

In a 'true' grid-forming inverter emulating a synchronous machine, the swing equation above directly governs the angle δ_a of the internal voltage source, based on the measured electrical power P_e. But it is also possible to take the same equation (in its equivalent form using per-unit frequency deviation ω_a) and turn this around into an 'inertia' control law for power exchange from a converter (which may be grid-following or grid-forming):

$$\hat{P}_e = P_0 - \frac{2H}{f_0} \cdot \frac{df}{dt}.$$

In this control law, P_0 is the undisturbed active power setpoint (dispatch instruction) and *df/dt* is a measurement of RoCoF in Hz/s obtained from a PLL or similar observer. The RoCoF is normalised by the nominal frequency f_0 = 50Hz and *H* then plays the role of a virtual inertia constant in seconds. The value $\hat{P}_e$ calculated by this control law becomes the conventional active power command to the converter.

The above control law may be regarded as implementing a form of synthetic inertia. However, its effect on the converter voltage source is indirect and inherently delayed, and arguably does not represent 'inertia' in the above sense on the shortest time scales. However, in a grid-forming converter it does arguably provide material support to the 'true' inertia function. Thus there are indications that OEMs may also be providing this function as an adjunct to grid-forming controls and using 'inertia' to describe either type of control, which can therefore be another source of confusion.

When considering synthetic inertial response from IBRs it will therefore be important to distinguish between that provided by direct angle control in a grid-forming converter, and that arising from a less direct control law using measured RoCoF, even if the same ‘inertia’ term is sometimes used for both. The latter may be better characterised as a ‘first derivative’ variety of fast frequency response, acting on transient time scales but not quasi-instantaneously as expected for true inertia response.

2. Study Inputs and Configuration

Simplified system modelling and simulation studies were undertaken using PSS/E software for the purpose of this investigation. At the level of detail being considered, the RMS framework provided by PSS/E is considered sufficient to represent salient features of interest, including comparative trajectories of frequency, RoCoF and active power flows in response to large disturbances. While EMT modelling and use of software such as PSCAD may deliver more raw accuracy in simulation results, these results are more difficult to interpret at high level and the additional detail provided is not expected to be material for the purpose of these studies. In an RMS framework, on the other hand, key variables such as frequencies and phase angle displacements are available as direct output quantities making the interpretation of results more tractable.

The following pages describe the development of the system model for studies, commencing with the steady state network representation in Sections 2.1 and 2.2, then the approach to dynamic modelling in Section 2.3 and brief comment on the simulation approach in Section 2.4.

2.1. Utopia-58 ‘Case 3’ Base System Scenario

To undertake forward-looking studies considering hypothetical future scenarios for a NEM-like system, a greatly simplified test system with broad characteristics matching the mainland NEM has been developed. The basis for this is a 58-bus test network dubbed Utopia-58 (‘utopia’ meaning ‘no place’ to emphasise it is not a true NEM model). A similar simplified model was previously used in studies by Vysus for the Australian Renewable Energy Agency [3].

The Utopia-58 test system was adapted by Vysus from a 59-bus, 14-generator power system model published by University of Adelaide researchers [2]. That latter model was developed to assist research in small-signal stability, hence focusses strongly on representing the network locations of 14 existing large synchronous plants in the circa-2000s NEM. The original authors in [2] stress that “the model should not be used to draw any conclusions relating to the actual performance” of the NEM and “the model is suitable for educational purposes / research-oriented analysis only”. These same caveats accordingly carry through to the system model used here.

For this study, the system model was adapted to represent a hypothetical post-2030 NEM scenario, with reduced levels of synchronous generation consistent with the ‘step change’ scenario in AEMO’s 2022 Integrated System Plan [4] and with very high penetration of inverter-based generation and battery storage resources. This base model configuration is denoted ‘Case 3’, as it is also used as such in separate scenario modelling by Vysus for AEMO.

The derived network model is shown schematically in Figure 1. It retains the three-digit bus numbering scheme in the original University of Adelaide model [2], which identifies corresponding regions of the mainland NEM as follows:

- 2xx: New South Wales region (‘NSW’).
- 3xx: Victoria region (‘VIC’).
- 4xx: Queensland region (‘QLD’).
- 5xx: South Australia region (‘SA’).

To provide for a suitable mix of strong and weak grid locations for generation and load, the original model has been augmented with a broad representation of the ‘West Murray’ region (northern VIC and southern NSW). The network has also been strengthened in places to represent transmission upgrades assumed in ISP post-2030 scenarios according to [4]; in particular, this includes a representation of the PEC interconnector between SA and NSW (via a phase-shifting transformer at bus 274, fixed at 30 degrees for the purpose of this study).

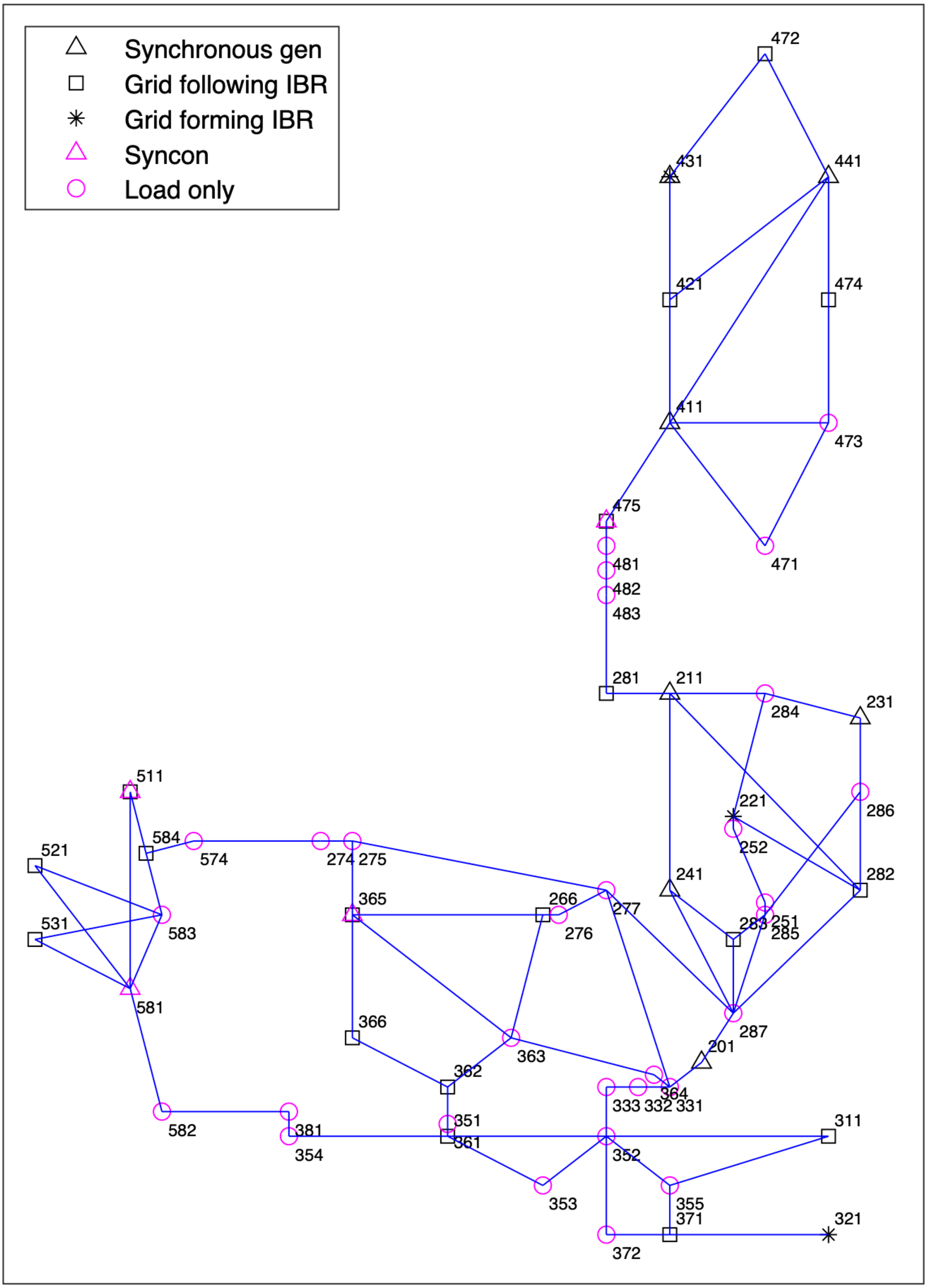


Figure 1 Utopia-58 test network in 'Case 3' base configuration

Numbered nodes in Figure 1, representing network busbars, bear symbols indicating the presence of generation or synchronous condensers at each busbar. Grid-following IBRs are distributed extensively throughout the system, while synchronous generators are present in NSW and QLD and absent from VIC and SA in this scenario (synchronous condensers remain present in these regions). Grid-forming IBRs appear at buses 221, 321 and 431; their inclusion is discussed further in the next section. Consistent with the greatly simplified level of representation, generator unit transformers are omitted. Circle symbols denote nodes with no (grid scale) generation connected.

The base power flow condition assumed for the study is derived from a north-south flow case for the original 14-generator system, with relatively high load in the SA and VIC regions. Load was scaled for the ISP post-2030 scenario and a portion reallocated to the West Murray equivalent region.

The basic load flow operating parameters for the 'Case 3' scenario are summarised in Table 1. A full PSS/E RAW and DYRE file listing for the base system is provided in the Appendix.

Table 1 Utopia-58 'Case 3' base operating scenario key parameters

	Total	NSW	VIC	QLD	SA
Load (MW)	33,500	15,000	8,000	7,000	3,500
Synchronous gen (MW)	8,000	4,000	–	4,000	–
Synch gen capacity (MVA)	12,000	7,000	–	5,000	–
Syncon (MVA)	1,500	500	250	125	375
Inverter based gen (MW)	26,376	12,000	7,640	3,700	3,036
Inverter capacity (MVA)	90,000	30,000	30,000	20,000	10,000
BESS capacity (MVA)	45,000	15,000	15,000	10,000	5,000
Synch inertia (MVA.s)	23,376	11,500	625	10,313	938
Inter-regional transfer (MW)	To NSW	–	–1,085	+545	–256
	To VIC	+1,085	–	–	–392
	To QLD	–545	–	–	–
	To SA	+256	+392	–	–

2.2. Derived Network Base Cases for Study

In order to compare the effect of different overall levels of synchronous inertia, as well as the effect of changing its geographic distribution across the system, the initial 'Case 3' scenario described in the previous section was developed into seven additional derived base cases as shown in Table 2 below.

Table 2 System base cases developed for comparative inertia study

Case	Brief desc.	Description
3	Base case	Initial base post-2030 scenario, high IBRs, low synchronous machines.
3a	Low mach	Reduction in all synchronous generation by 50% pro-rata, halving MVA ratings and effective inertia, and shifting MW generation to adjacent IBRs.
3b	Syncon only	Removal of all synchronous generation, shifting MW to adjacent IBRs, but leaving syncons in service.
3c	No mach	Removal of all synchronous generation and syncons, shifting MW generation to adjacent IBRs.

3d	QLD conc	Same overall synchronous generation MW and MVA as in Case 3, but shifted to concentrate all synchronous generation in QLD region.
3e	VIC conc	Same overall synchronous generation MW and MVA as in Case 3, but shifted to concentrate all synchronous generation in VIC & southern NSW.
3f	QLD low	Reduction in all synchronous generation by 50% from Case 3d.
3g	VIC low	Reduction in all synchronous generation by 50% from Case 3e.

The specific levels of synchronous generator capacity and synchronous inertia in each case are summarised in the following table. Note that a fixed quantity of synthetic inertial response is additionally present in all cases, as detailed in Section 2.3.3 below.

Table 3 Synchronous generation and inertia in developed base cases

	Synch generation capacity (MVA)				Synchronous inertia* (MVA.s)			
	NSW	VIC	QLD	SA	NSW	VIC	QLD	SA
3	7000	–	5000	–	11500	625	10313	938
3a	3500	–	2500	–	6375	625	5313	938
3b	–	–	–	–	1250	625	313	938
3c	–	–	–	–	–	–	–	–
3d	–	–	12000	–	1250	625	24313	938
3e	4000	8000	–	–	7250	25125	313	938
3f	–	–	6000	–	1250	625	12313	938
3g	2000	4000	–	–	4250	12875	313	938

* Synchronous inertia figures are inclusive of synchronous condensers, fixed in all cases except Case 3c.

It may be noted from Table 3 that the geographically concentrated Cases 3d and 3e have a somewhat higher overall level of synchronous inertia than the original Case 3, considering a raw summation of inertia across the system. Likewise, Cases 3f and 3g have more overall synchronous inertia than the equivalent Case 3a. This will have important consequences for the interpretation of study results later in this report.

2.3. Generic Plant Modelling

2.3.1. Synchronous Machines

The modelling of synchronous generators and their controls in all cases follows that for the same generators in the original University of Adelaide system [2]. These all use standard elements within the PSS/E model library.

For present study purposes the most important parameters are the size in MVA and the inertia constant *H* for each aggregated plant, which are provided for the initial 'Case 3' configuration in Table 4. It should be noted that the inertia constants *H* for these generators have been deliberately reduced from their values in the original University of Adelaide models (and the presumed values of the corresponding plants in the real NEM) in order better to represent hypothetical future operating conditions with very low synchronous inertia.

Table 4 Summary parameters for synchronous generators in base cases

Busbar	Size (MVA)	Inertia *H* (s)	Subtransient X'' (pu)
201	4000	1.5	0.25
211	1000	1.5	0.21
231	1000	1.5	0.25
241	1000	1.25	0.21
411	1500	2.0	0.25
431	1500	2.0	0.25
441	2000	2.0	0.24

Further details of the synchronous plant models and their configuration can be obtained from [2] and the DYRE listing in the Appendix.

All synchronous generators are given a machine ID of 'M' in the PSS/E load flow cases. For the developed base cases, the generators as listed in Table 4 are modified as follows:

- Cases 3b and 3c: all are omitted;
- Case 3d: generators in the NSW region are omitted and the three QLD generators are resized to 4000MVA apiece, for the same overall MVA in total;
- Case 3e: all but the generator at bus 201 are omitted, and additional synchronous generators placed at VIC bus 311 (5000MVA, H = 2.8s) and bus 321 (3000MVA, H = 3.5s) for the same overall MVA in total;
- Cases 3a, 3f and 3g: MVA rating of all synchronous generators is reduced by 50% from those in cases 3, 3d and 3e respectively.

The modelling of synchronous condensers follows a generic approach using a standard full-order machine model ('GENROU') from the PSS/E library and an AC type excitation system model ('ESAC4A'). This is broadly similar to the approach taken for the modelling of South Australia synchronous condensers in AEMO's OPDMS.

Table 5 below summarises the sizing and inertia constants of synchronous condensers for this study. The configuration is the same in all base cases, excepting Case 3c that omits all synchronous machines.

Table 5 Summary parameters for synchronous condensers in base cases

Busbar	Size (MVA)	Inertia *H* (s)	Subtransient X'' (pu)
201	250	2.5	0.152
211	250	2.5	0.152
365	250	2.5	0.152
475	125	2.5	0.152
511	125	2.5	0.152
581	250	2.5	0.135

All synchronous condensers are given a machine ID of 'Q' in the PSS/E load flow cases.

2.3.2. Grid-Following IBRs: GENINV model

The majority of IBRs included in the base cases are of grid-following nature and comprise a mixture of inverter-based generation (with machine ID of 'I' in the PSS/E cases) and battery storage (with machine ID of 'B'). Battery storage plants are configured to be quiescent in the steady state (zero active power exchange) and may adjust to either positive (discharge) or negative (charging) power exchange dynamically, while generators are assumed never to drop active power below zero. In other respects the configuration of grid-following generators and BESS plants is essentially identical, apart from the assumed frequency droop as stated below.

The dynamic model used for all grid-following IBRs is the 'GENINV' model from Vysus' internal library. This is based on a generic grid-following inverter control scheme which is illustrated in Figure 2. At its core is a fast current controller that operates in a synchronous α–β reference frame aligned with the grid terminal voltage V_t. The current controller generates the PWM voltage source components E_α, E_β in the same reference frame. The inputs to the current control are a 'reactive' current command $\hat{I}_\beta$ determined from closed-loop control of the grid voltage V_t, and an 'active' current $\hat{I}_\alpha$ determined from closed-loop control of the inverter DC bus voltage V_{dc}. The DC input P_{dc} to the inverter is assumed to be obtained from an energy source with a scheduled power level P_{ref} and an adjustment ΔP calculated by a power-frequency droop characteristic.

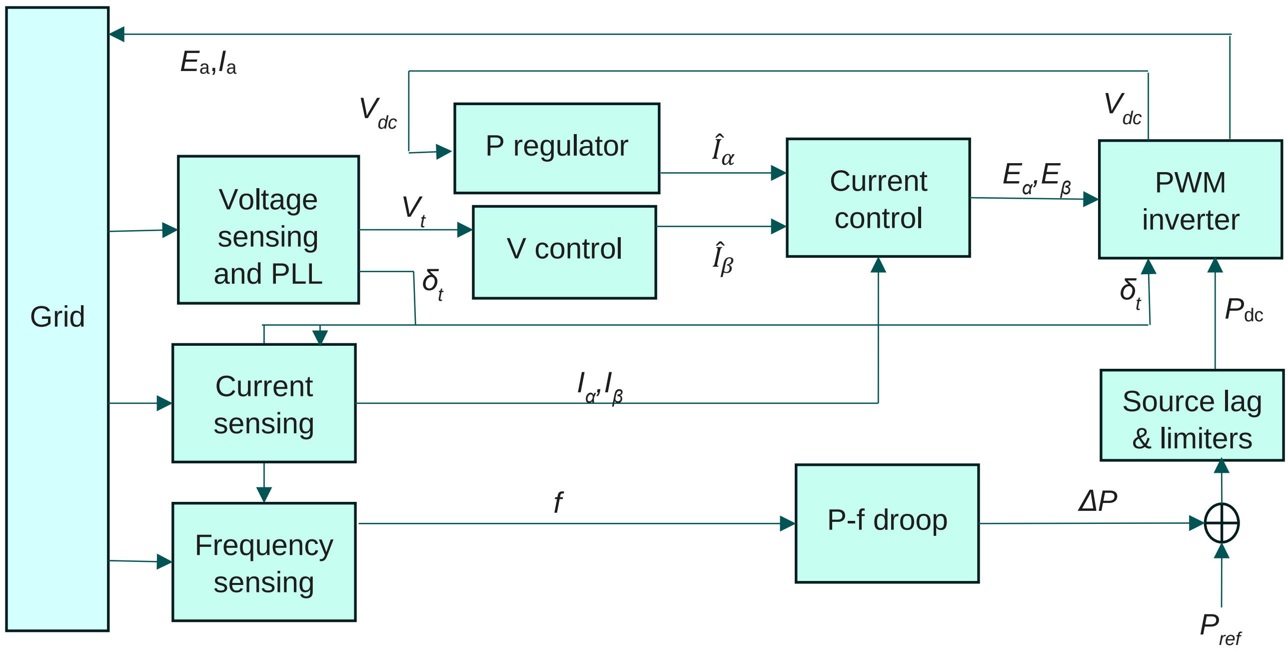


Figure 2 Generic grid-following inverter model (GENINV)

In the PSS/E model GENINV, the input power P_{dc} is subject to the PMAX and PMIN value limits specified in the load flow case, and for a BESS may be negative, indicating charging. The power-frequency droop curve is a programmable 8-point piecewise linear characteristic, and in this study is set to reproduce a 5% frequency droop for generators and a 1.7% frequency droop for BESS plants, each with a ±0.15Hz deadband. (While more aggressive deadbands are used in the NEM at present, IBR frequency response is not a focus for the current study.)

2.3.3. Grid-Forming IBRs: VSMINV model

All base cases include three grid-forming IBR aggregates connected in the VIC, NSW and QLD regions with basic parameters shown in Table 6 below. The overall capacity of grid-forming IBRs corresponds to 8.9% of IBR generation capacity in the system base case, and 5.9% of total IBR capacity including BESS.

Additional grid-forming IBR capacity is used in Case 3c, to account for the removal of all synchronous plant including synchronous condensers. This includes the conversion of 1000MVA of BESS in South Australia to grid-forming operation. In Case 3c, grid-forming IBRs correspond to 10.3% of generation capacity.

Table 6 Summary parameters for grid-forming IBRs in base cases

Busbar	Size (MVA)	Inertia *H* (s)	Transient X' (pu)
221	2000	3.5	0.2
321	2000	3.5	0.2
431	4000*	3.5	0.2
521†	1000	3.5	0.2

* Owing to the displacement of synchronous generation, the MVA capacity of this generator in certain derived cases increases up to a maximum of 5500MVA.

† Grid-forming in Case 3c only.

Although the grid-forming plant at bus 431 is considered to be a generator aggregate and the others as BESS aggregates, the three plants are otherwise configured and modelled identically.

The grid-forming IBRs in Table 6 contribute synthetic inertial response in the system models and have been determined as the approximate minimum required, considering both size and location, in order for all eight base cases to remain stable in an undisturbed steady state (including in particular those with no synchronous machines). While their inclusion is not essential for stable behaviour in all cases, their configuration as in Table 6 is replicated across all cases (with qualifications as above) to provide a consistent baseline for comparison, controlling for a nearly fixed level of synthetic inertial response while the quantum of synchronous inertia is varied. To control further for the presence or absence of synthetic inertial response, sensitivity cases are included with the study results that compare the behaviour when grid-forming IBRs are removed and replaced with grid-following IBRs.

The grid-forming IBRs are identified in the PSS/E load flow cases with machine ID 'I' for generators or 'B' for BESS. They are dispatched at zero MW in the undisturbed steady state in the initial 'Case 3' configuration, but in the other developed configurations receive some positive generation or discharge displaced from synchronous generation.

The dynamic model used for grid-forming IBRs is the 'VSMINV' model from Vysus' internal library. This is a generic model for a virtual synchronous machine, with a control scheme depicted in simplified form in Figure 3.

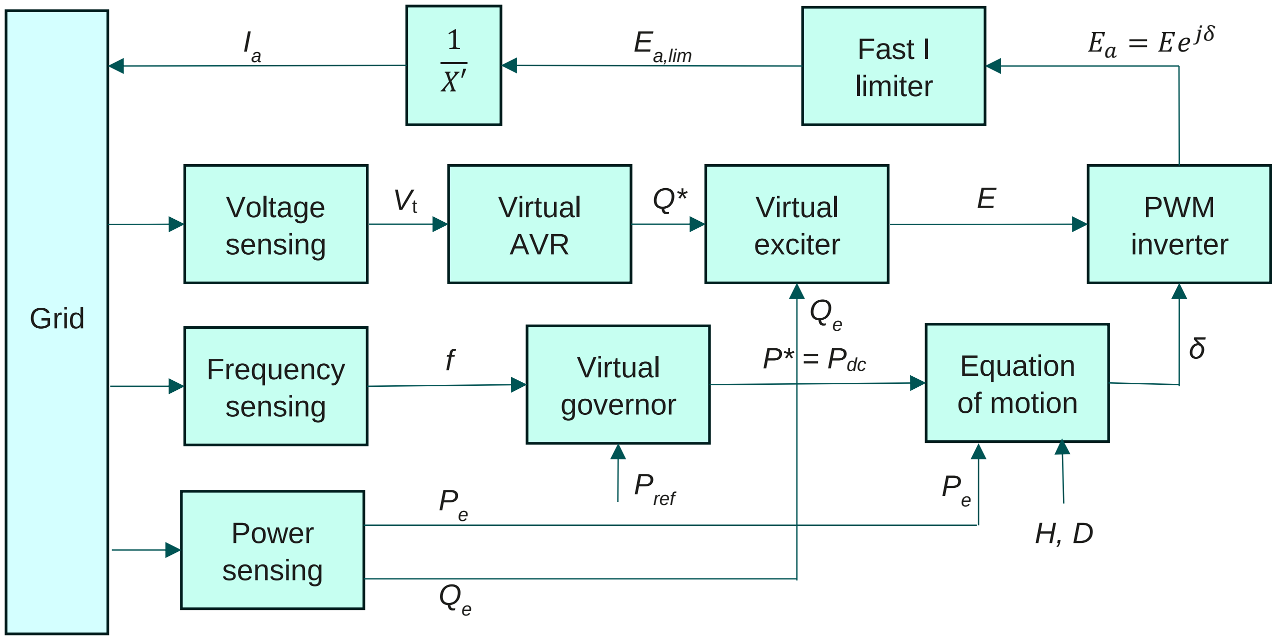


Figure 3 Simplified schematic of generic grid-forming model (VSMINV)

Generically, the virtual AVR and governor may implement a PID control law or a droop characteristic. The equation of motion in the PSS/E model provides for both inertia H and virtual damping D, although for study purposes here the latter is set to zero.

Grid-forming converters that present a voltage source to the grid require fast-acting protective controls to limit the magnitude of output current below the instantaneous capability of the switching devices. The VSMINV model includes basic logic to rapidly reduce the amplitude of the PWM source voltage E_a when necessary to hold the magnitude of injected current I_a below a prescribed limit. This hard limit is configured by default in this study as 1.5 times the nominal current when producing full MW output at unity power factor and at nominal voltage.

2.3.4. Statcom

The original University of Adelaide system model contains a number of Statcom units throughout the network, represented in dynamic simulations by PSS/E's built-in CSTATT model. These are employed for local voltage support and are not considered to be material to the inertia dynamics in this study.

Only one of these Statcoms is retained in the present system model, located at bus 471 (corresponding to the Brisbane load centre) and with a size of 250Mvar. The CSTATT configuration settings may be obtained from the DYRE listing in the Appendix.

2.4. Study Approach

All eight study cases as described above went through a standard checking process in PSS/E to confirm suitability for study, in particular:

- Load flow in a solved condition with realistic network voltage profile.
- Reactive power loadings on generators and BESS where appropriate are sensible and within bounds. (Local voltage profiles were fine tuned where necessary to reshape reactive power flows.)

- Interconnector flows rechecked for consistency with the base Case 3, to verify that re-dispatch of active power has been undertaken correctly where relevant.
- Successful generator conversion and TYSL solution with total mismatch 0.02MVA or less.
- Basic DYRE checks that loaded models are consistent with configuration of generators in load flow.
- Successful simulation start with either no suspect initial conditions, or at most two initial states moving in the range of 1% to 10% of initial value per second and attributable to the initial value being close to zero. (The latter was generally observed only for case 3c.)
- Successful 'flat run' in dynamics for 60 seconds with no applied disturbances.

The default configuration was used for all PSS/E solution parameters excluding the following:

- Simulation time step DELT adjusted from 0.01s to 0.001s, as is typical for simulations with IBRs.
- Frequency filter time constant adjusted from 0.04s to 0.01s. (A minimum of one half cycle is considered prudent as a realistic time scale for internal frequency calculations.)
- Maximum solution iterations before non-convergence adjusted from 25 to 200.

A relatively conservative default load characteristic, comprising 50% constant-power and 50% constant-current, was assumed for study purposes.

In order to simulate generator rejection events of prescribed size, an IBR generator aggregate in each of the VIC and QLD regions is notionally split into two aggregates at the same busbar, identical apart from size. The aggregate of the requisite size was given the machine ID 'J' while the second aggregate with the balance retained the machine ID 'I'.

More specifically,

- To simulate a large generator unit loss in VIC, a notional 4000MVA / 1000MW inverter-based generator at bus 351 is split into one 1000MVA / 500MW aggregate unit (ID 'J') and one 3000MVA / 500MW aggregate unit (ID 'I'). Tripping unit 'J' thus models a 500MW generator rejection (with a 1000MVA simultaneous reduction in IBR capacity).

- To simulate a large generator unit loss in QLD, a notional 4000MVA / 1000MW inverter-based generator at bus 475 is split into one 1000MVA / 600MW aggregate unit (ID 'J') and one 3000MVA / 400MW aggregate unit (ID 'I'). Tripping unit 'J' thus models a 600MW generator rejection (with a 1000MVA simultaneous reduction in IBR capacity).

The key metrics used for comparative study of inertia effects in the study results are the following:

- Maximum RoCoF observed in the region of the disturbance and in a second region, within the first second after an initial subtransient period immediately following the disturbance.

- Maximum absolute deviation in frequency in the region of the disturbance and in a second region, within the first second after an initial subtransient period immediately following the disturbance.

- Maximum difference in voltage phase angle between two remotely interconnected regions (for example QLD and SA, or NSW and SA after a QLD separation) within the first second.

The reference busbars used for frequency, voltage and angle measurement purposes are 201 for NSW, 311 for VIC, 411 for QLD and 511 for SA.

A subtransient period of at most four cycles (80ms) at onset of the disturbance is ignored in order to exclude RMS simulation artefacts that can affect the raw frequency variables in the short term but may not represent real system effects. These effects are observable in the simulation results and are discussed further in the next section.

3. Results and Analysis

3.1. Generator Rejection Events

3.1.1. VIC Region – 500MW Disturbance

When simulating the sudden loss of a 500MW generating unit in the VIC region, all system cases other than 3b (syncons only) and 3e (synchronous generator concentration in VIC) produced stable results for the period immediately following the disturbance. The result from case 3b was unstable, while case 3e produced an underdamped oscillatory response for the VIC frequency which is attributable to slight mistuning of stabiliser controls. (Absence of pole slipping was verified by inspection.)

In general, case 3b (synchronous condensers only) produces a highly oscillatory response for VIC regional frequency following most large disturbances. This may be partly attributable to mistuning of excitation controls and the degree of simplicity in the system models, but also points to the difficulty of obtaining robust system configurations with very low levels of inertia, whether synchronous or synthetic. On the other hand case 3c, which omits the synchronous condensers but includes one additional GFM plant in the SA region, was found to be less susceptible to oscillatory behaviour.

Figure 4 and Figure 5 depict the simulation results for VIC frequency in all cases except the oscillatory case 3b. Overall it is found that in this system the frequencies in the VIC, NSW and SA regions are closely coherent but the QLD frequency has slightly different behaviour. Accordingly, Figure 6 and Figure 7 provide plots of the QLD frequency response for comparison.

Key metrics for VIC and QLD frequency and for system-wide voltage angle deviation in the five stable cases are summarised in Table 7.

Table 7 Summary metrics for 500MW VIC generator rejection

Case	VIC max RoCoF (Hz/s)	VIC max Δf (Hz)	QLD max RoCoF (Hz/s)	QLD max Δf (Hz)	QLD-SA max Δangle (deg)
3 – base	0.125	0.0348	0.025	0.0084	85.8
3a – lo mach	0.175	0.0355	0.050	0.0073	85.5
3c – no mach	0.525	0.0403	0.775	0.0205	79.5
3d – QLD conc	0.275	0.0411	0.025	0.0082	84.9
3e – VIC conc	0.275	0.0597	0.025	0.0072	84.2
3f – QLD low	0.250	0.0412	0.025	0.0077	84.7
3g – VIC low	0.300	0.0581	0.150	0.0053	83.7

As noted in the previous section, the figures in Table 7 are exclusive of an initial subtransient period where a very brief but substantial drop in the reported frequency is apparent, and brought out most clearly at right in Figure 5. The shape of this deviation is sensitive to the setting used for the frequency filter time constant in PSS/E, and appears to be a consequence of the way PSS/E processes short-term changes in network voltage phase angles into inferred frequency variations. As such it is best considered as a simulation artefact and not material for real-world frequency behaviour, relative to frequency movements detectable over a time scale of 0.1s or greater.

The reported metrics agree at high level with intuitive considerations for behaviour of low-inertia systems. Overall, cases with lower synchronous inertia exhibit higher RoCoF and larger short-term frequency deviations from nominal. However the results also reveal the importance of geographic location of synchronous inertia. Thus in Cases 3d and 3e, the overall synchronous inertia is greater than in Case 3, yet the peak RoCoF in VIC is greater while that in QLD is essentially unchanged. In VIC, the maximum deviation in frequency is also larger when synchronous inertia is concentrated than when it is distributed more evenly across the system.

Figure 8 shows the trajectory of active power flow across the QNI interconnector (from QLD to NSW region) resulting from the disturbance in each case. The ultimate post-contingent flow is seen to be dependent on both the geographic distribution of generation and relative inertia levels on each side of the interconnector, broadly consistent with first principles for primary response (keeping in mind that governor modelling is highly simplified for this study).

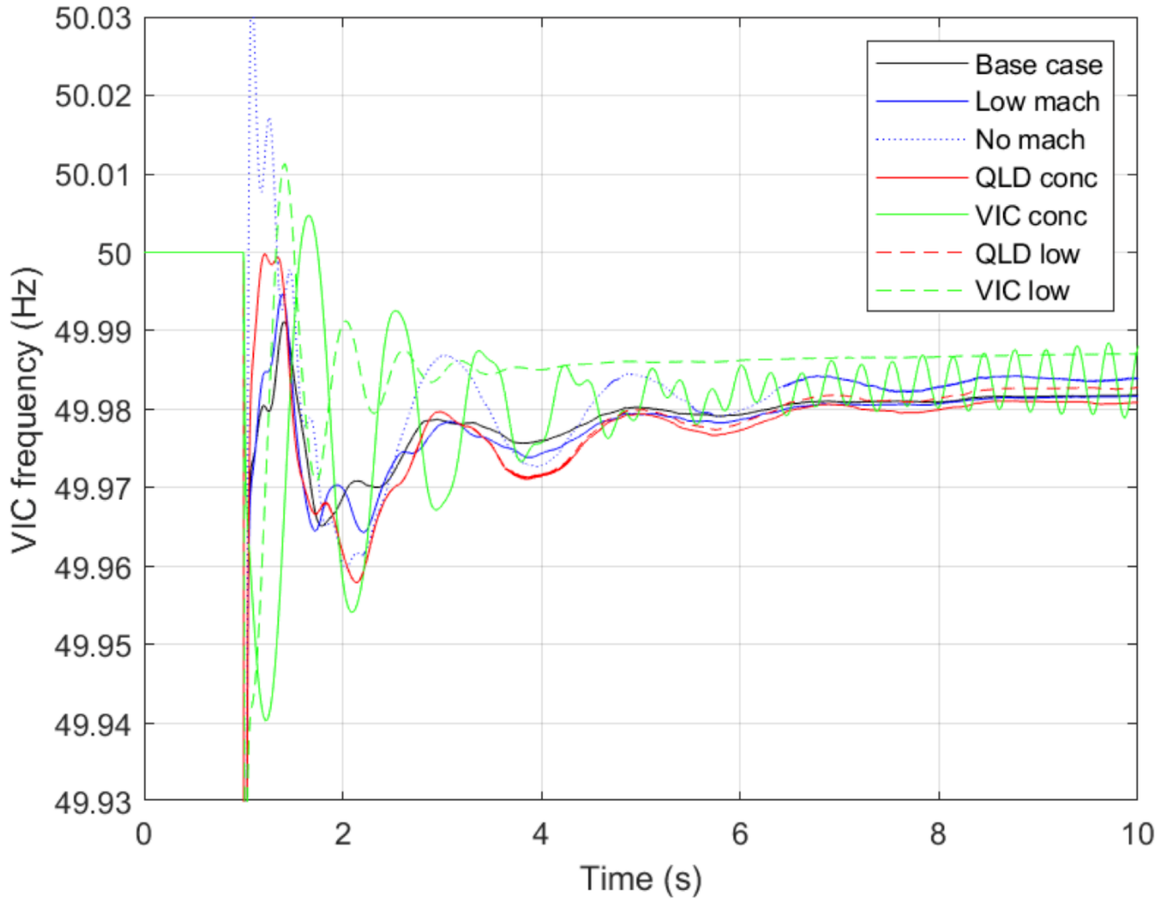


Figure 4 Frequency response in VIC to 500MW VIC generator loss

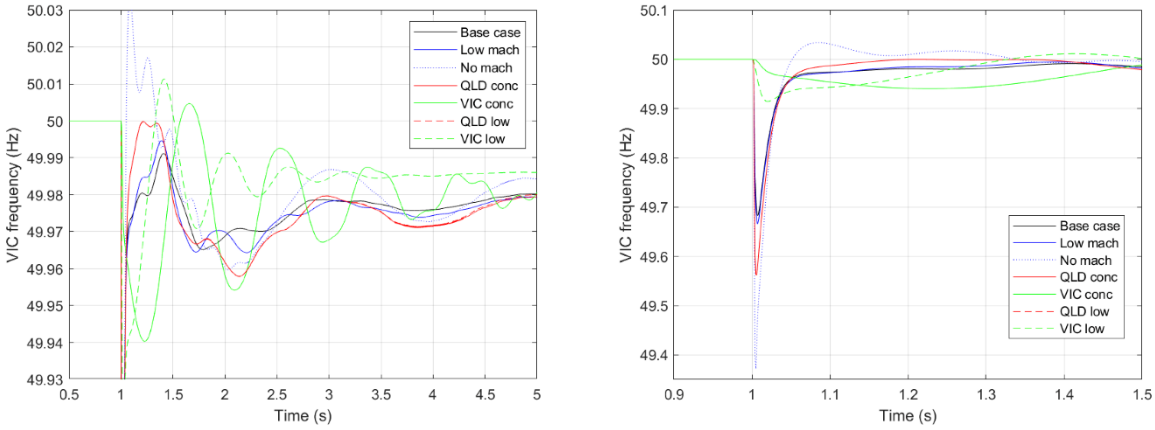


Figure 5 Detail of Figure 4

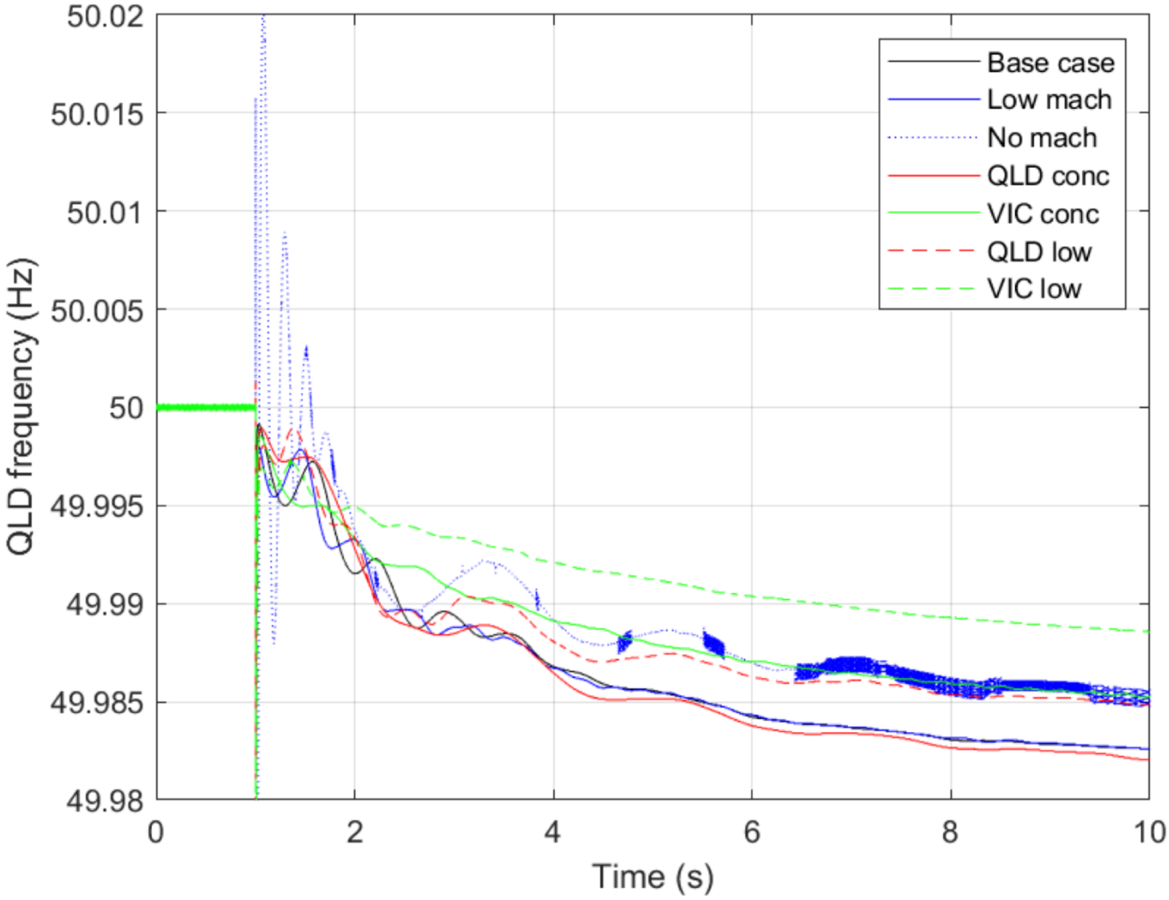


Figure 6 Frequency response in QLD to 500MW VIC generator loss

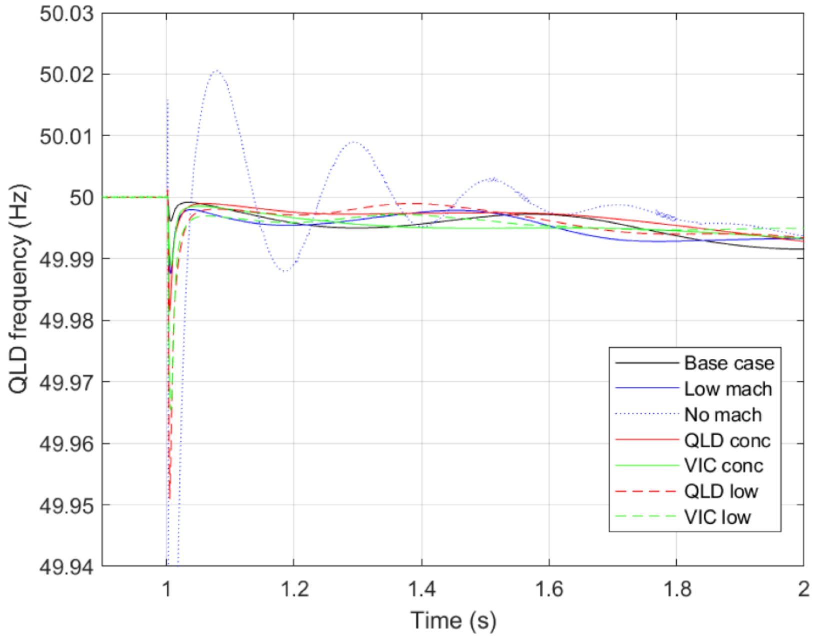


Figure 7 Detail of Figure 6

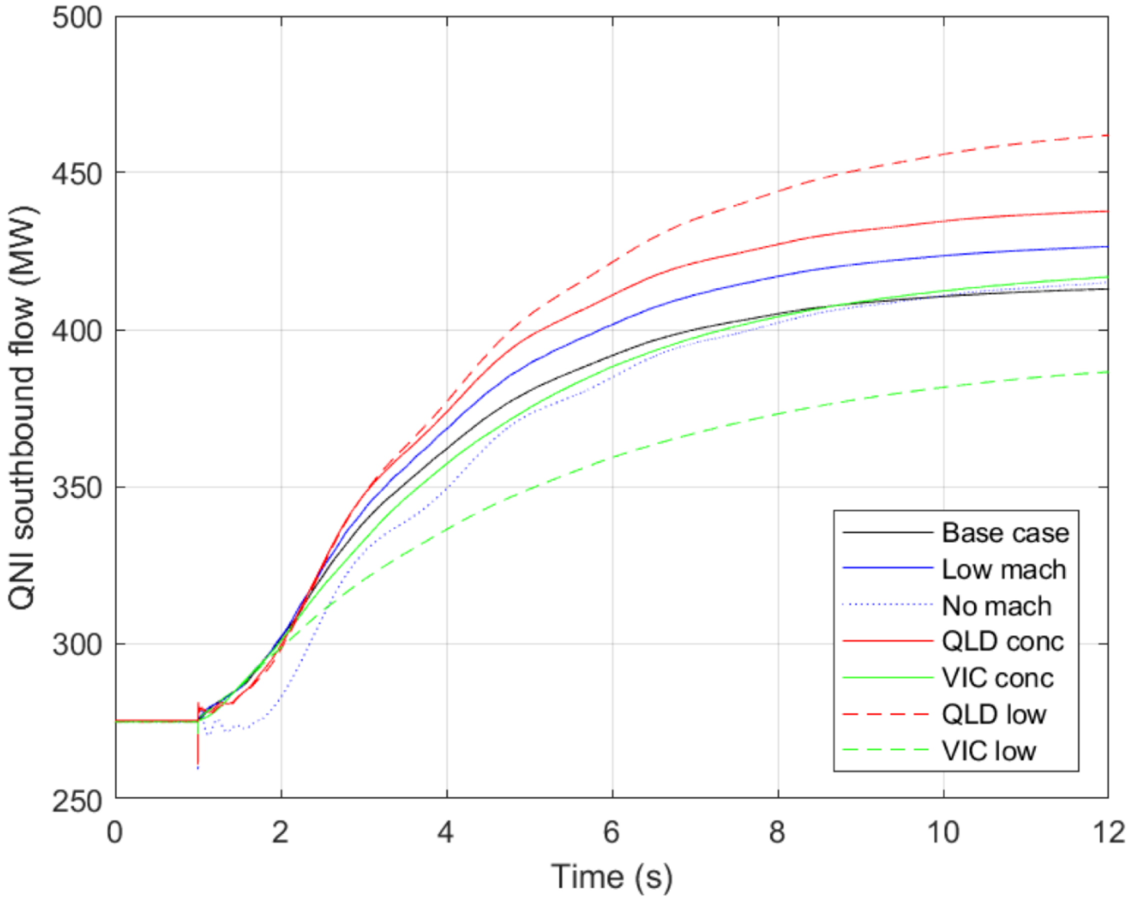


Figure 8 QLD to NSW active power flow response to 500MW VIC generator loss

It is also evident that the system behaviour in Case 3c, where all synchronous machines are removed and the system relies entirely on grid-forming IBRs, is qualitatively of a different nature to the remaining cases, at least at transient level. As with the synchronous condensers in Case 3b, this in part reflects the fact that only limited control system tuning has been undertaken for the grid-forming plants, and that the representation is greatly simplified (in particular, no power oscillation damping capability is included). But it also underlines the intuitive understanding that operation of a fully electronic power system is qualitatively different than when operation relies at least in part on electromechanical principles.

3.1.2. QLD Region – 600MW Disturbance

When simulating a 600MW generating unit trip in the QLD region, all base cases likewise yielded (initially) stable behaviour apart from Case 3b – syncon only which produced highly oscillatory behaviour for VIC frequency. Although the longer term frequency response is not the subject of this study, it may be noted that Case 3d (QLD concentration) displayed slow damping of frequency oscillations and ultimately gave way to a secondary instability from T = 3.5s onward. This issue was not apparent in the equivalent Case 3f with lower synchronous inertia, and it may be that Case 3d could be further optimised to give an acceptable longer term response.

Figure 9 and Figure 10 illustrate the response of the QLD region frequency to the 600MW unit trip in all cases, while Figure 11 and Figure 12 illustrate the response of the VIC region frequency (which is representative of the balance of the system) for all cases but the unstable Case 3b. The responses are qualitatively similar to the 500MW VIC unit trip results in the previous section.

The table summarises the key metrics for QLD and VIC frequency and system angle deviation for this disturbance.

Table 8 Summary metrics for 600MW QLD generator rejection

Case	QLD max RoCoF (Hz/s)	QLD max Δf (Hz)	VIC max RoCoF (Hz/s)	VIC max Δf (Hz)	QLD-SA max Δangle (deg)
3 – base	1.150	0.1595	0.025	0.0098	75.2
3a – lo mach	1.575	0.1696	0.050	0.0096	74.0
3b – s'con only	3.175	0.0887	(oscillatory)	0.0537	71.7
3c – no mach	1.175	0.0320	0.625	0.0213	69.8
3d – QLD conc	0.775	0.1273	0.050	0.0100	76.4
3e – VIC conc	1.200	0.1010	0.050	0.0106	70.7
3f – QLD low	1.550	0.1708	0.075	0.0097	74.5
3g – VIC low	1.225	0.1016	0.050	0.0092	70.7

It is seen that for this disturbance in the QLD region, concentration of synchronous generation in QLD or in VIC leads to a faster RoCoF in VIC, but otherwise does not appear to have a material detrimental effect on inertia response. It therefore appears that the effect of synchronous inertia concentration on inertia response – good or bad – can be dependent on the location of a large disturbance. The RoCoF overall is disproportionately higher for this event than for the 500MW VIC disturbance.

Figure 13 shows the trajectory of QLD to NSW active power flow across the interconnector for each system case.

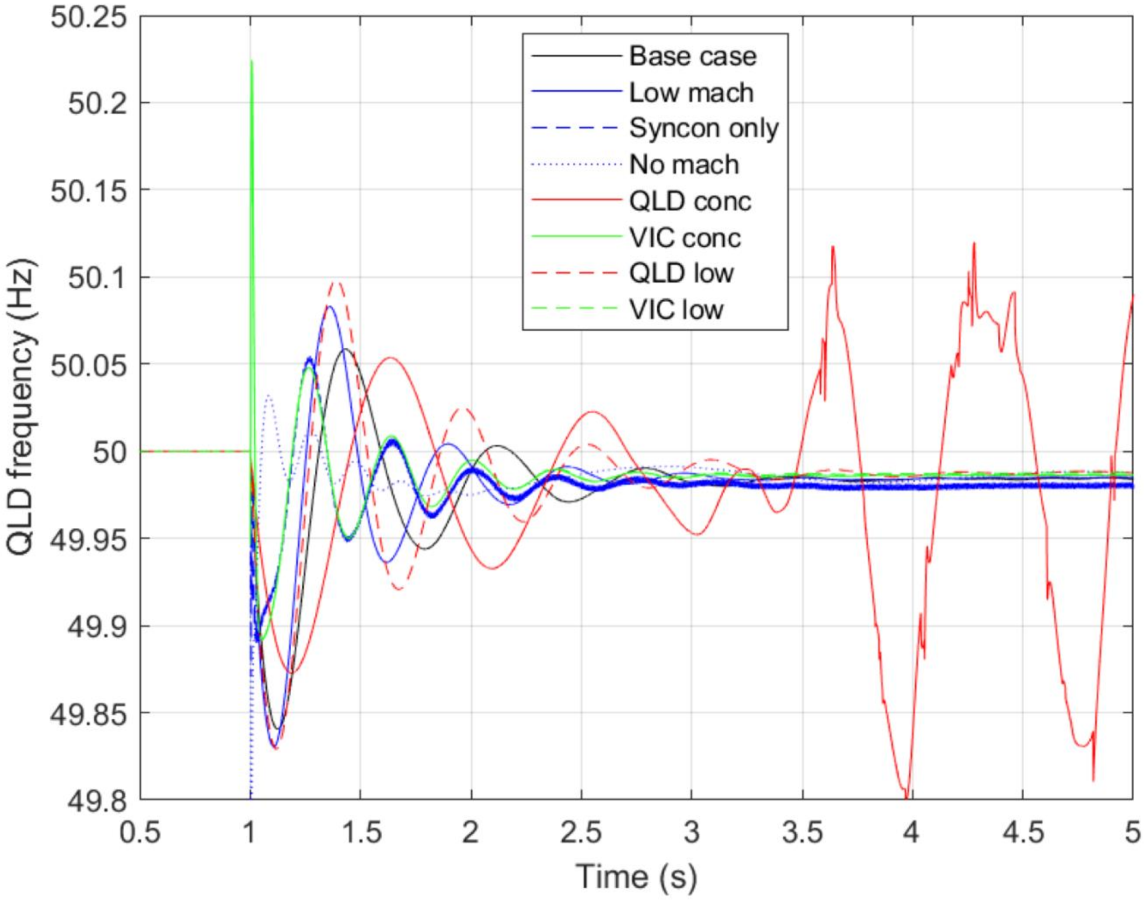


Figure 9 Frequency response in QLD to 600MW QLD generator loss

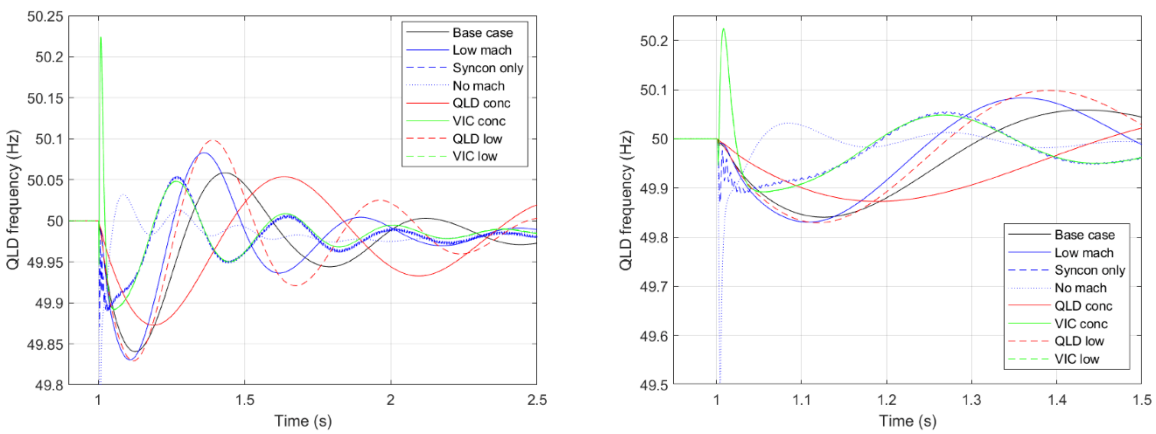


Figure 10 Detail of Figure 9

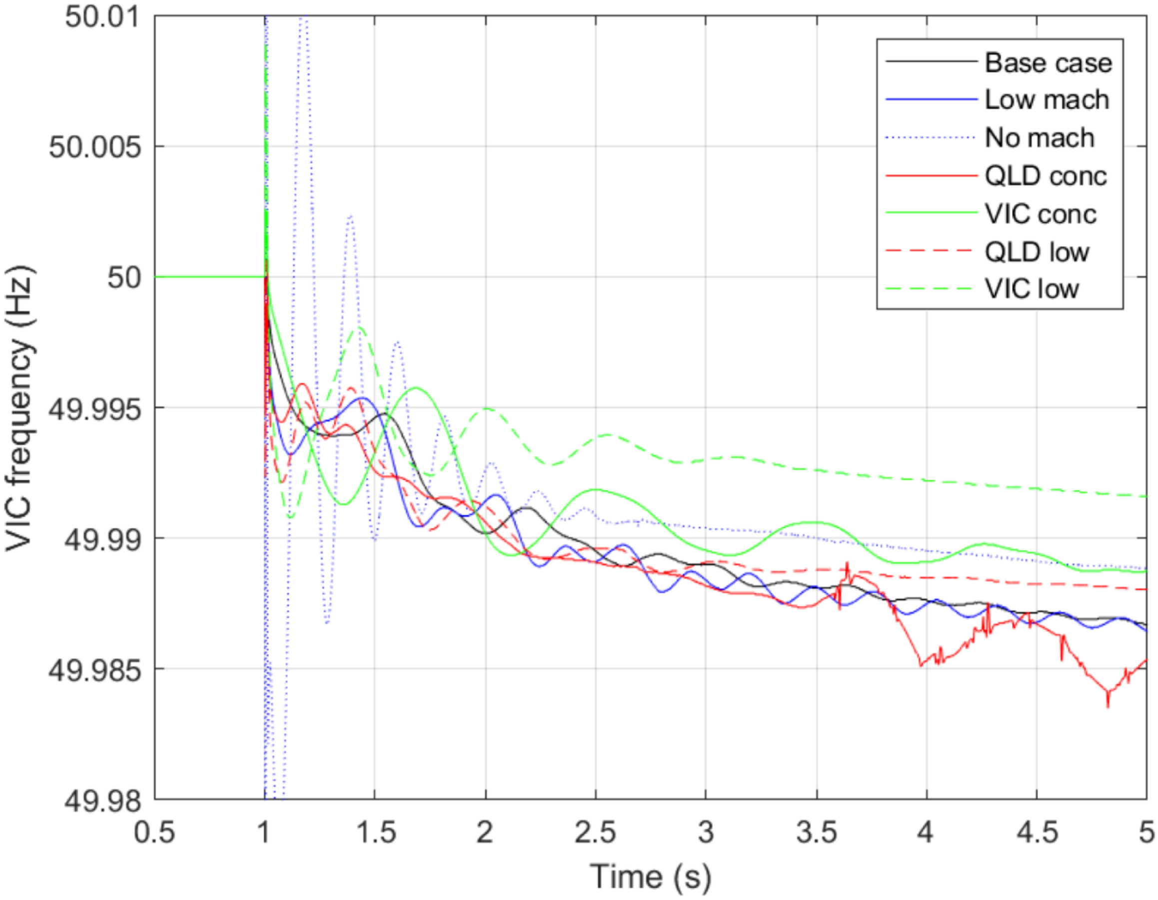


Figure 11 Frequency response in VIC to QLD 600MW generator loss

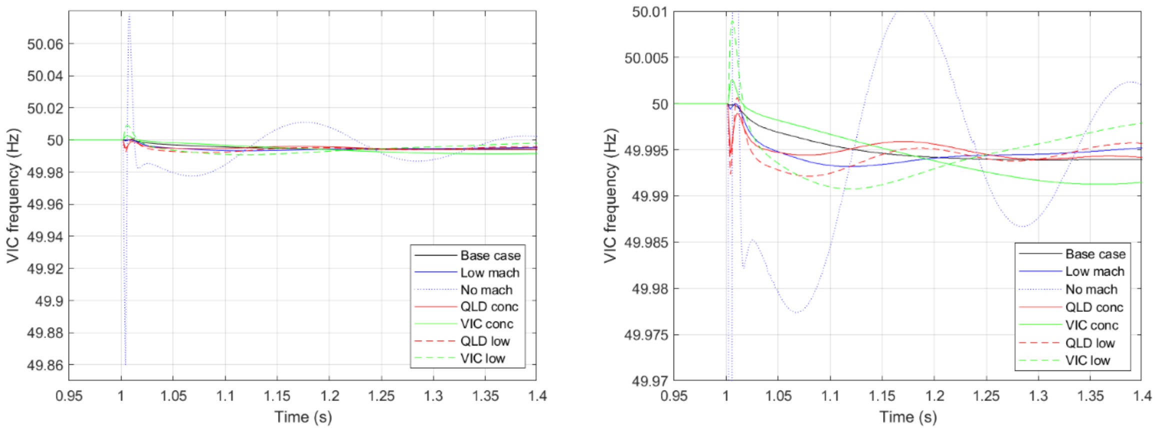


Figure 12 Detail of Figure 11

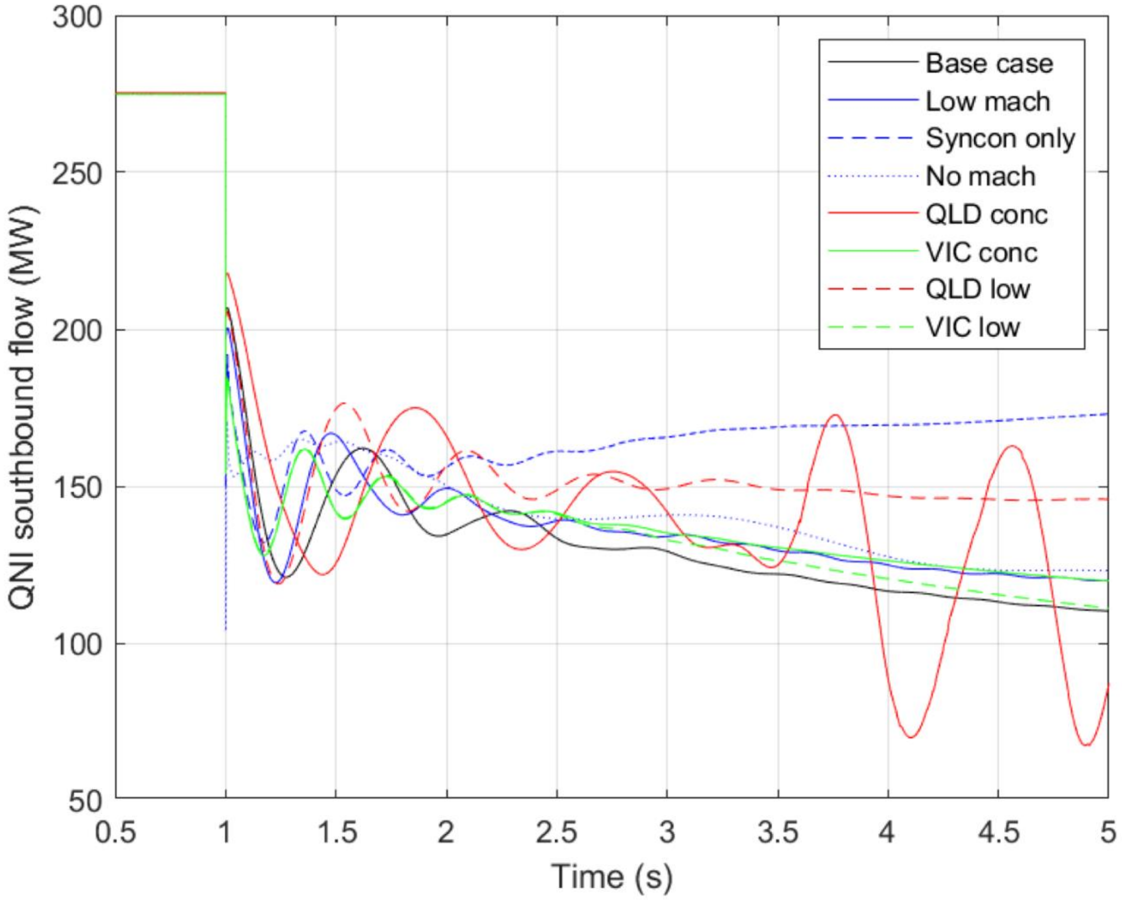


Figure 13 QLD to NSW active power response to QLD 600MW generator loss

3.2. Load Rejection Events

3.2.1. VIC Region: 363MW load rejection

Meaningful simulation results for load rejection events were obtained for all cases other than case 3b, which returned a highly oscillatory VIC frequency. Load rejections were simulated by forcing a load aggregate instantaneously out of service within the relevant region.

Figure 14 and Figure 15 show the response of VIC frequency to the tripping of 363MW of load in VIC, while Figure 16 and Figure 17 show the response of QLD frequency to the same event. Key metrics are summarised in Table 9.

Table 9 Summary metrics for 363MW VIC load rejection

Case	VIC max RoCoF (Hz/s)	VIC max Δf (Hz)	QLD max RoCoF (Hz/s)	QLD max Δf (Hz)	QLD-SA max Δangle (deg)
3 – base	0.075	0.0230	0.025	0.0059	77.1
3a – lo mach	0.100	0.0242	0.025	0.0054	77.1
3c – no mach	0.225	0.0189	0.525	0.0062	77.0
3d – QLD conc	0.150	0.0234	0.025	0.0057	77.0
3e – VIC conc	0.150	0.0357	0.125	0.0048	77.3
3f – QLD low	0.150	0.0234	0.025	0.0052	76.9
3g – VIC low	0.225	0.0365	0.250	0.0035	77.2

The transient overfrequency response is qualitatively as expected – a brief, sharp transient lasting two or three cycles (considered a PSS/E artefact) followed by a conventional high frequency swing and decay to a post-contingent steady state above 50Hz.

There is again a predictable inverse relationship between RoCoF in both VIC and QLD and the overall level of synchronous inertia, but superimposed on this once again is a noticeable adverse effect (in both regions) from concentrating synchronous machines either in QLD or in VIC/NSW. As with the results for generator rejection, Case 3e (VIC/NSW concentration) develops an underdamped frequency oscillation in response to a VIC region load rejection, which may be attributed to mistuning of generator damping controls. The oscillatory behaviour is not present in the equivalent case 3g (VIC low) where the quantum of synchronous generation is reduced; however, a more severe initial overfrequency transient is evident in the latter case.

Figure 18 shows the trajectory of QLD to NSW interconnector active power flow in response to the VIC region load rejection. By inspection, this is seen to be essentially a mirror image of Figure 8 for the equivalent generator contingency. Again, the dependence on both generator location and relative inertia levels is evident.

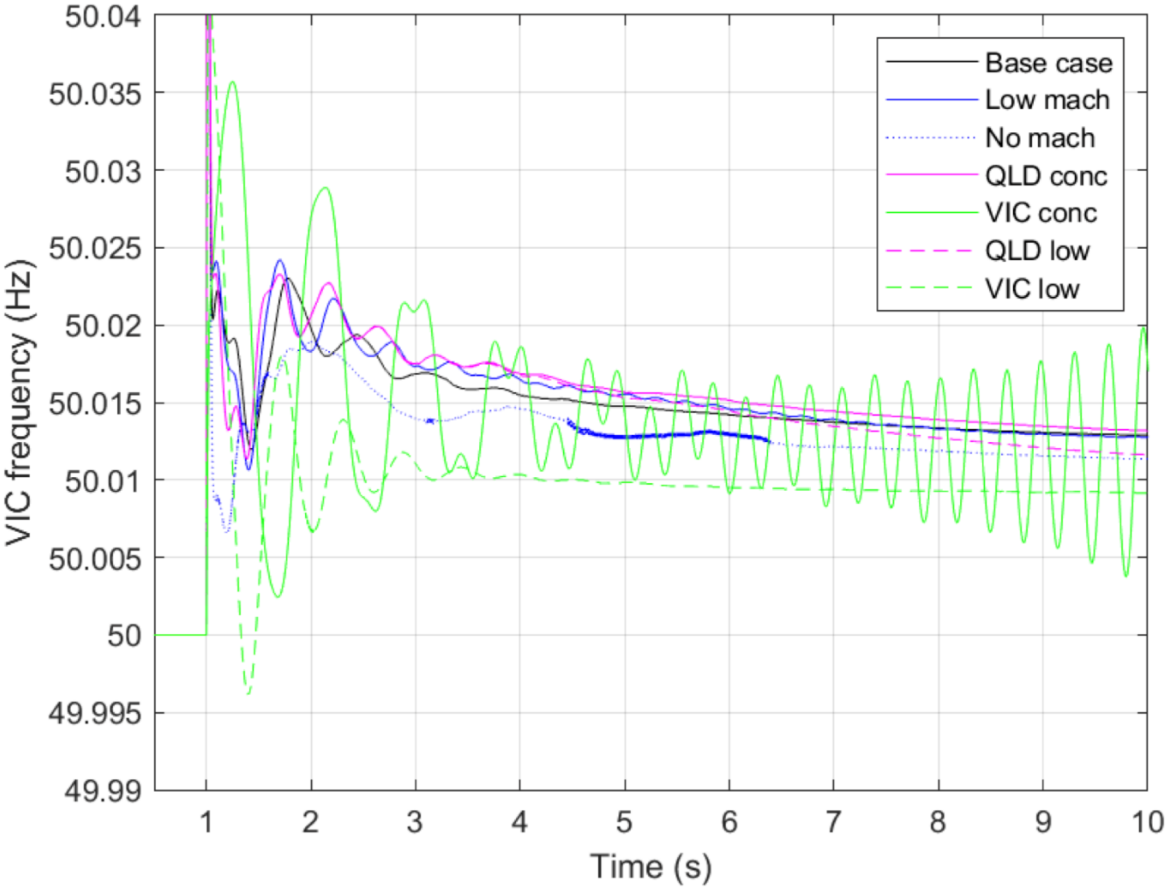
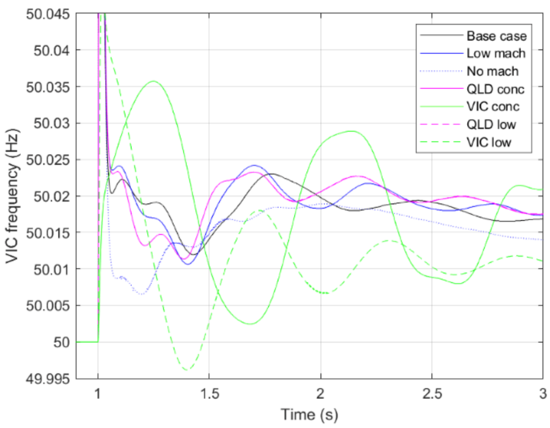


Figure 14 Frequency response in VIC to VIC 363MW load rejection



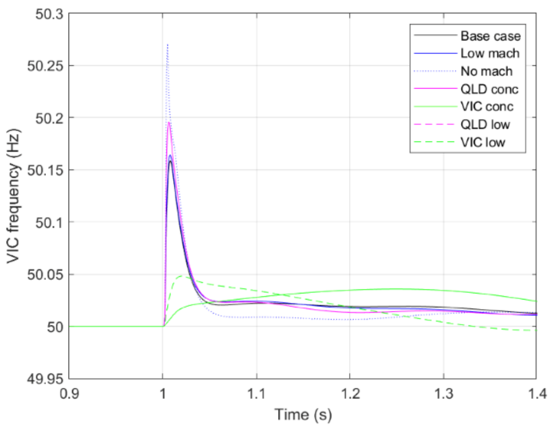


Figure 15 Detail of Figure 14

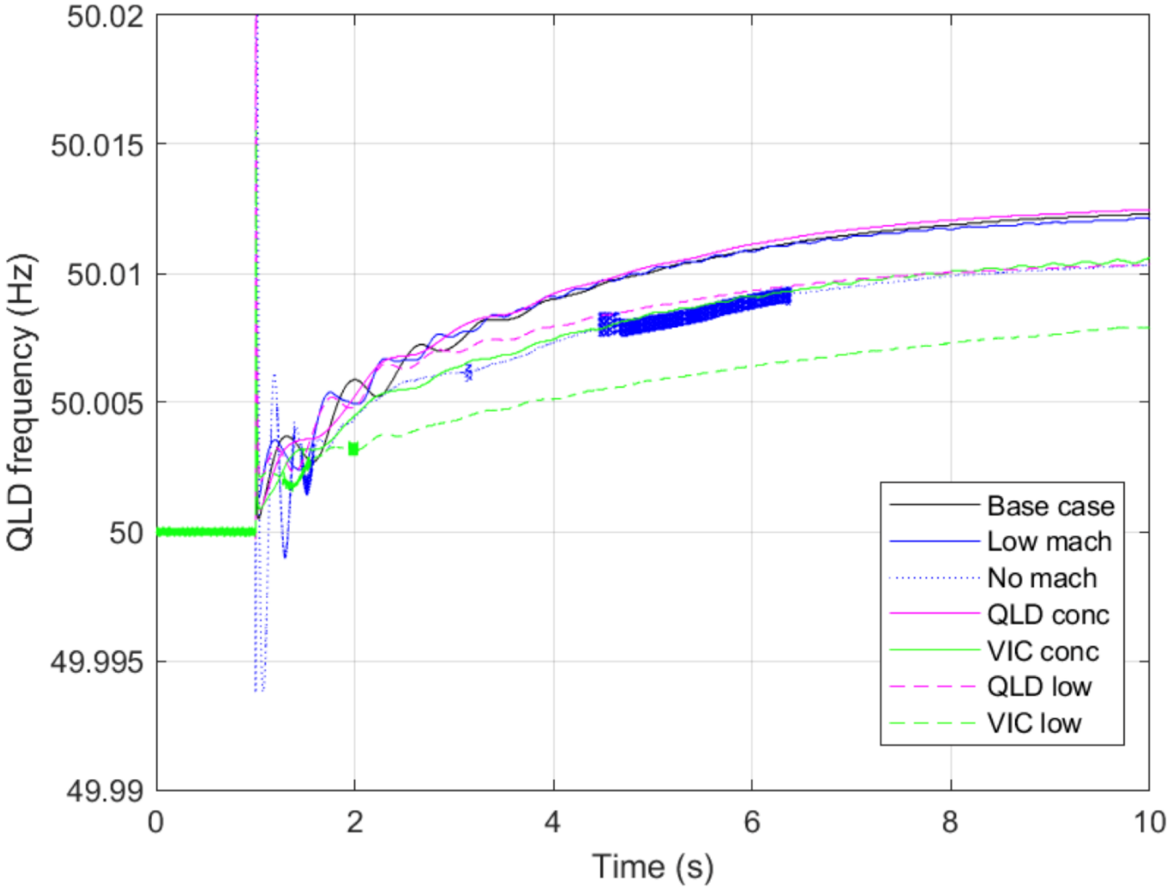


Figure 16 Frequency response in QLD to VIC 363MW load rejection

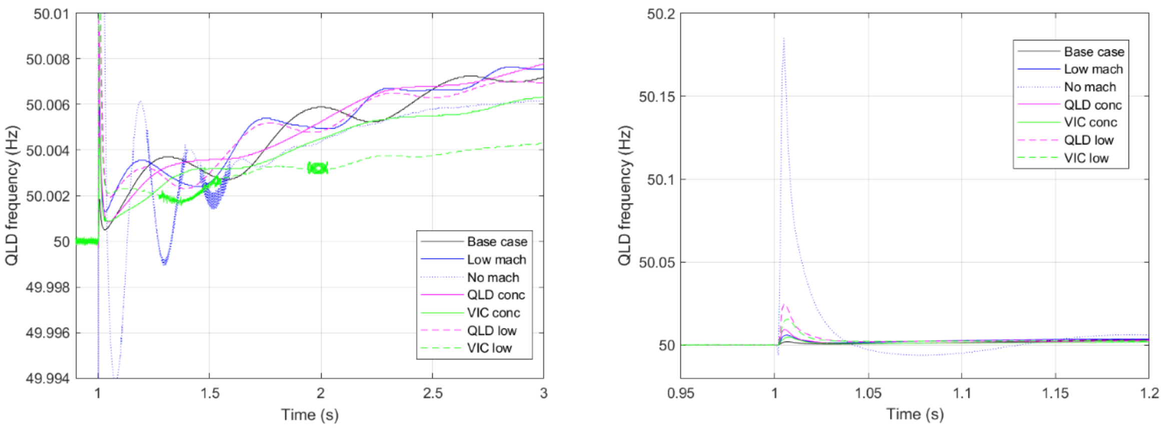


Figure 17 Detail of Figure 16

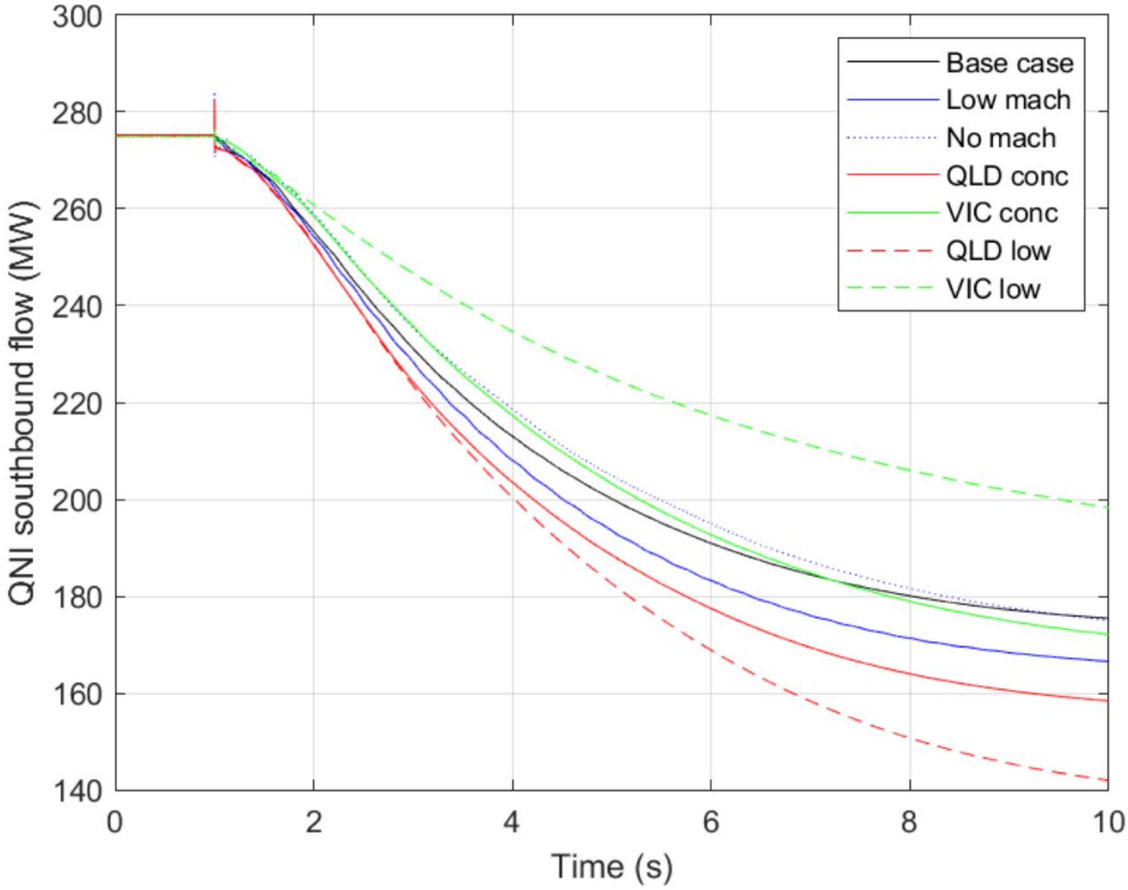


Figure 18 QLD to NSW active power flow response to VIC 363MW load rejection

3.2.2. QLD Region: 400MW load rejection

Figure 19 and Figure 20 show the response of QLD frequency to a 400MW sudden load rejection in the QLD region. Figure 21 and Figure 22 show the response of VIC frequency to the same event. Again, all cases other than 3b return stable results for the initial post-contingent period, though in Case 3d a secondary instability develops around the 3 second mark (not dissimilar to that for the generator rejection).

Table 10 summarises the key system metrics for this 400MW QLD load rejection.

Table 10 Summary metrics for 400MW QLD load rejection

Case	QLD max RoCoF (Hz/s)	QLD max Δf (Hz)	VIC max RoCoF (Hz/s)	VIC max Δf (Hz)	QLD-SA max Δangle (deg)
3 – base	0.575	0.0839	0.100	0.0036	85.6
3a – lo mach	0.775	0.0905	0.100	0.0032	84.7
3b – s'con only	1.550	0.0253	(oscillatory)	0.0264	84.5
3c – no mach	0.725	0.0144	0.575	0.0164	84.7
3d – QLD conc	0.375	0.0668	0.075	0.0033	85.0
3e – VIC conc	0.500	0.0324	0.025	0.0039	84.7

3f – QLD low	0.800	0.0897	0.100	0.0032	84.4
3g – VIC low	0.525	0.0327	0.050	0.0036	84.7

In this scenario there is evidence for an apparent slight beneficial effect of synchronous generator concentration. Concentrating synchronous inertia in VIC and removing from QLD, as well as vice versa, has a noticeable positive effect on the initial response of both QLD and VIC frequency to this event (disregarding secondary effects). The full reason for this is unclear but warrants further investigation.

Figure 23 shows the QLD to NSW active power flow across the interconnector in response to the QLD load rejection event. This is seen to be largely a mirror image of Figure 13 for the equivalent (if slightly larger) generator contingency.

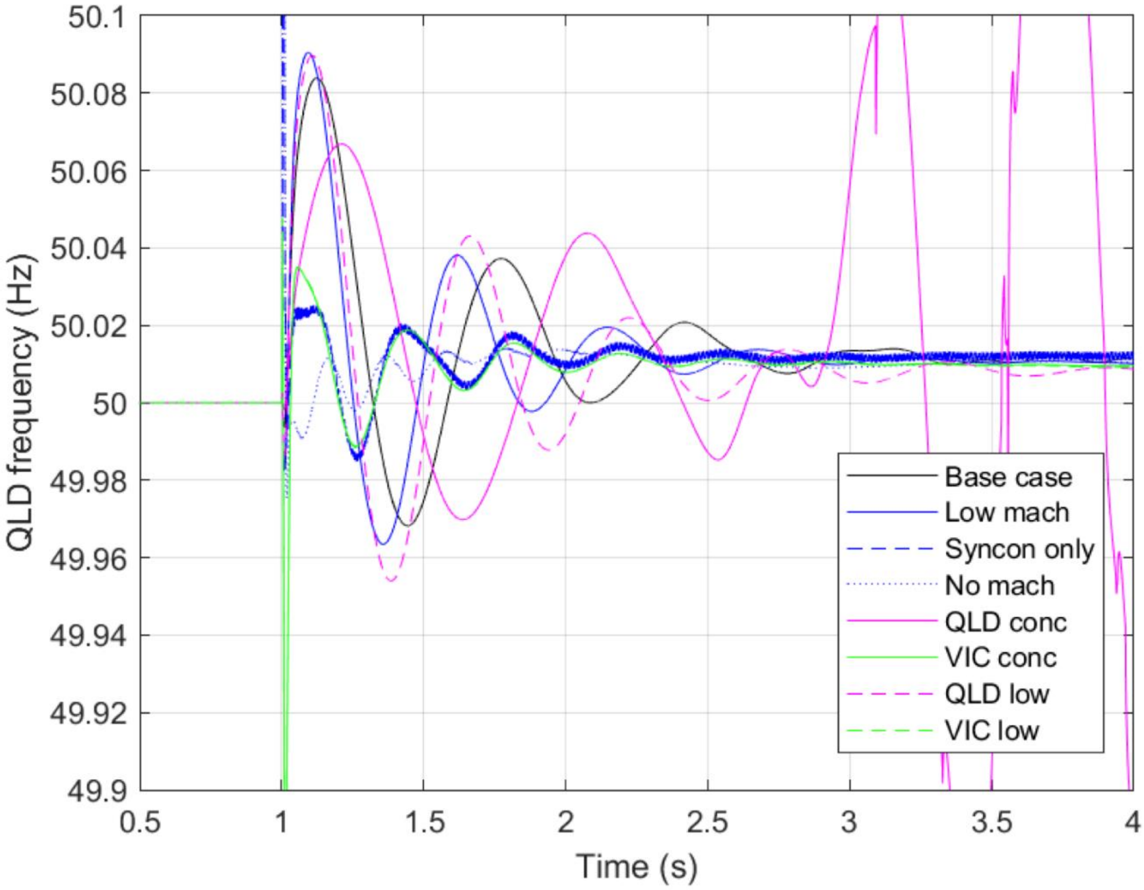


Figure 19 Frequency response in QLD to QLD 400MW load rejection

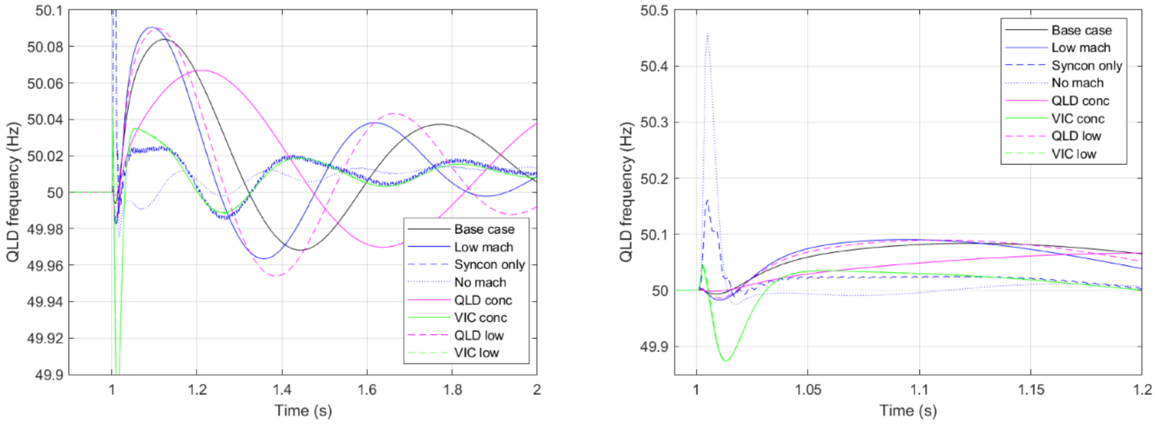


Figure 20 Detail of Figure 19

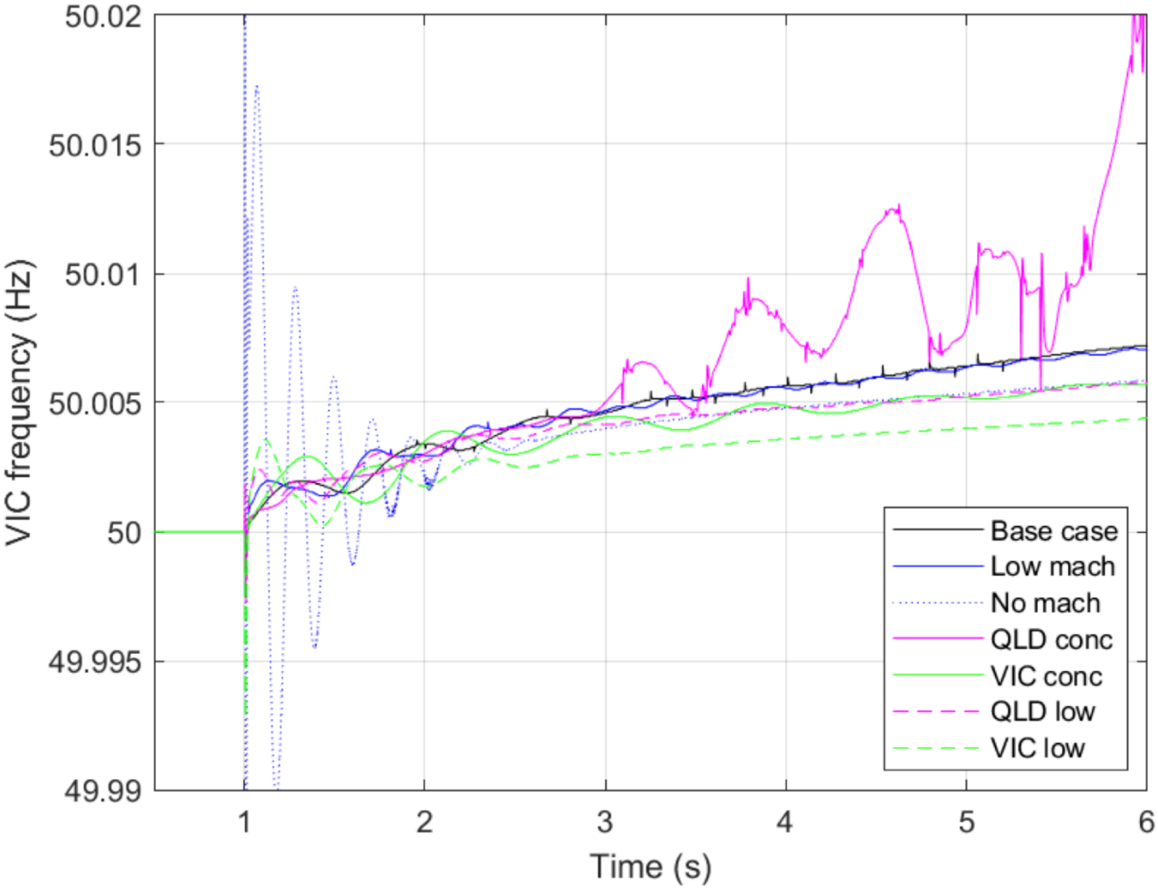


Figure 21 Frequency response in VIC to QLD 400MW load rejection

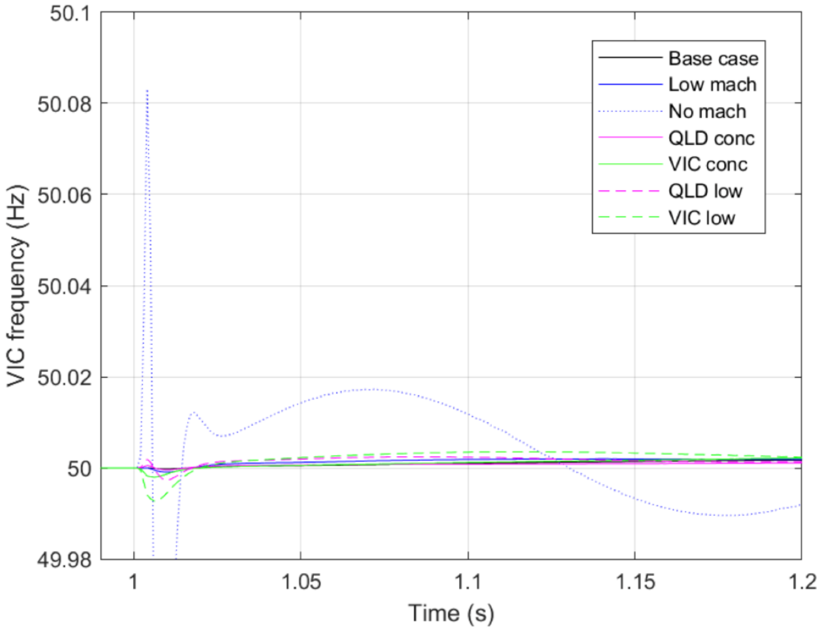


Figure 22 Detail of Figure 21

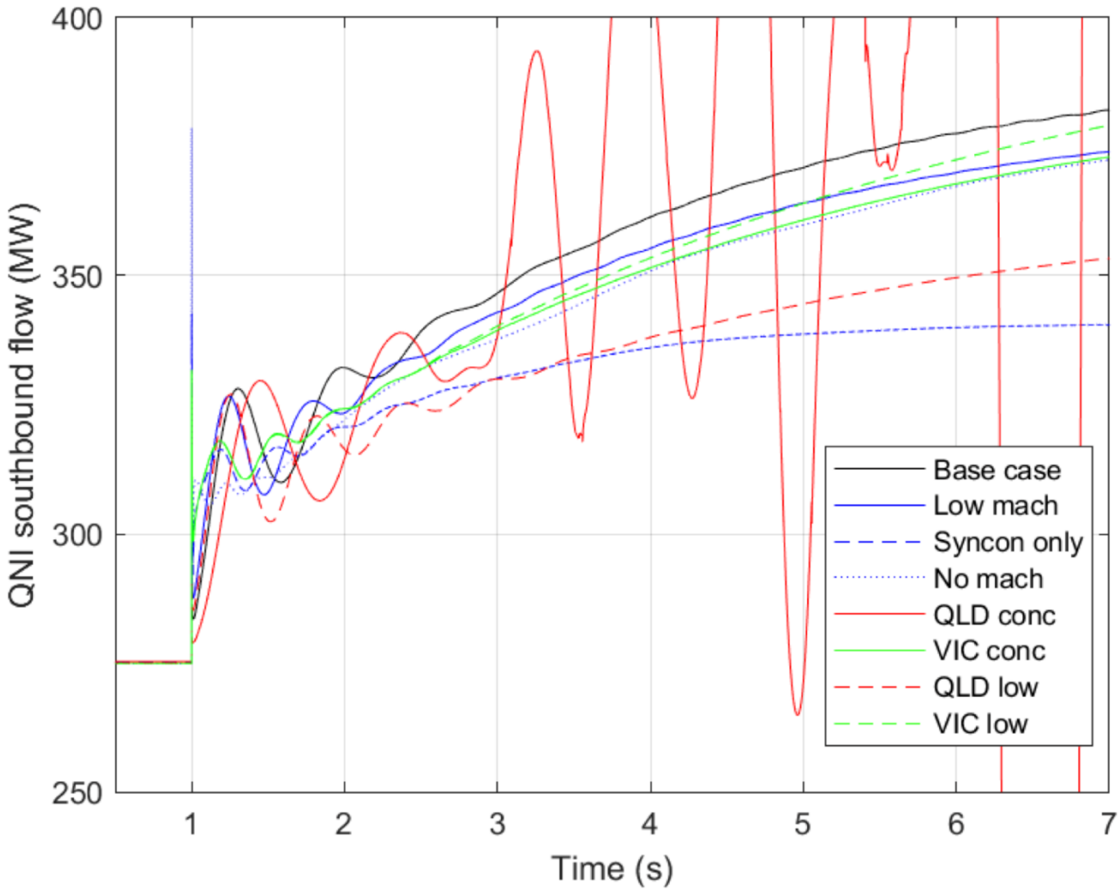


Figure 23 QLD to NSW active power flow response to QLD 400MW load rejection

3.3. System Separation Event: QLD – NSW Interconnector Trip

A system separation event is simulated by opening the single circuit between buses 475 and 481 in the QLD region, corresponding to the northern end of the QNI interconnector.

In their standard configuration, the base cases not giving a stable response to this event are the following:

- Case 3b (syncons only): results in highly oscillatory frequency in VIC region (as for other large disturbances).
- Case 3d (QLD concentration of synchronous machines): initial response stabilises but a secondary instability develops after T = 3 seconds (similar to QLD contingency events as above).
- Case 3f (QLD concentration with lower inertia): QLD region fails to stabilise due to cascading unit trips, however balance of system is stable.

Notably, stable responses are obtained in cases 3b, 3c, 3e and 3g, which remove all synchronous generation from QLD, so that after separation this region relies solely on grid-forming IBRs and (except in case 3c) one synchronous condenser.

Figure 24 and Figure 25 illustrate the response of QLD frequency to this event in each case, while Figure 26 and Figure 27 illustrate the response of VIC frequency. Table 11 summarises the key system metrics for these cases (noting that as QLD is separated, the NSW to SA angle difference is used in place of the QLD to SA angle difference).

Table 11 Summary metrics for QLD-NSW system separation

Case	QLD max RoCoF (Hz/s)	QLD max Δf (Hz)	VIC max RoCoF (Hz/s)	VIC max Δf (Hz)	NSW-SA max Δangle (deg)
3 – base	1.750	0.2325	0.075	0.0210	30.5
3a – low mach	2.475	0.2637	0.100	0.0216	30.4
3b – s'con only	2.250	0.1497	(oscillatory)	0.1358	31.1
3c – no mach	2.075	0.1273	0.275	0.0192	29.5
3d – QLD conc	0.975	0.1742	0.225	0.0243	30.6
3e – VIC conc	2.250	0.1855	0.075	0.0237	30.6
3f – QLD low	3.000	0.3084	0.150	0.0243	30.6
3g – VIC low	2.250	0.1847	0.075	0.0180	30.4

Interestingly, the effect of removing synchronous generators from QLD to VIC in this situation is to slightly improve the frequency excursion performance in QLD. This is likely a contingent effect of the particular configuration of grid-forming IBRs and one should not rely too heavily on this conclusion.

As expected, reducing the synchronous inertia in VIC/NSW worsens the RoCoF behaviour in this region but does not affect behaviour in the separated QLD region.

In some cases there is evidence of underdamping of the VIC frequency post-contingency, which is presumed to result from minor mistuning of synchronous machine damping controls and the simplified representation of these controls in the system model. This is not considered to materially affect the conclusions of the present study.

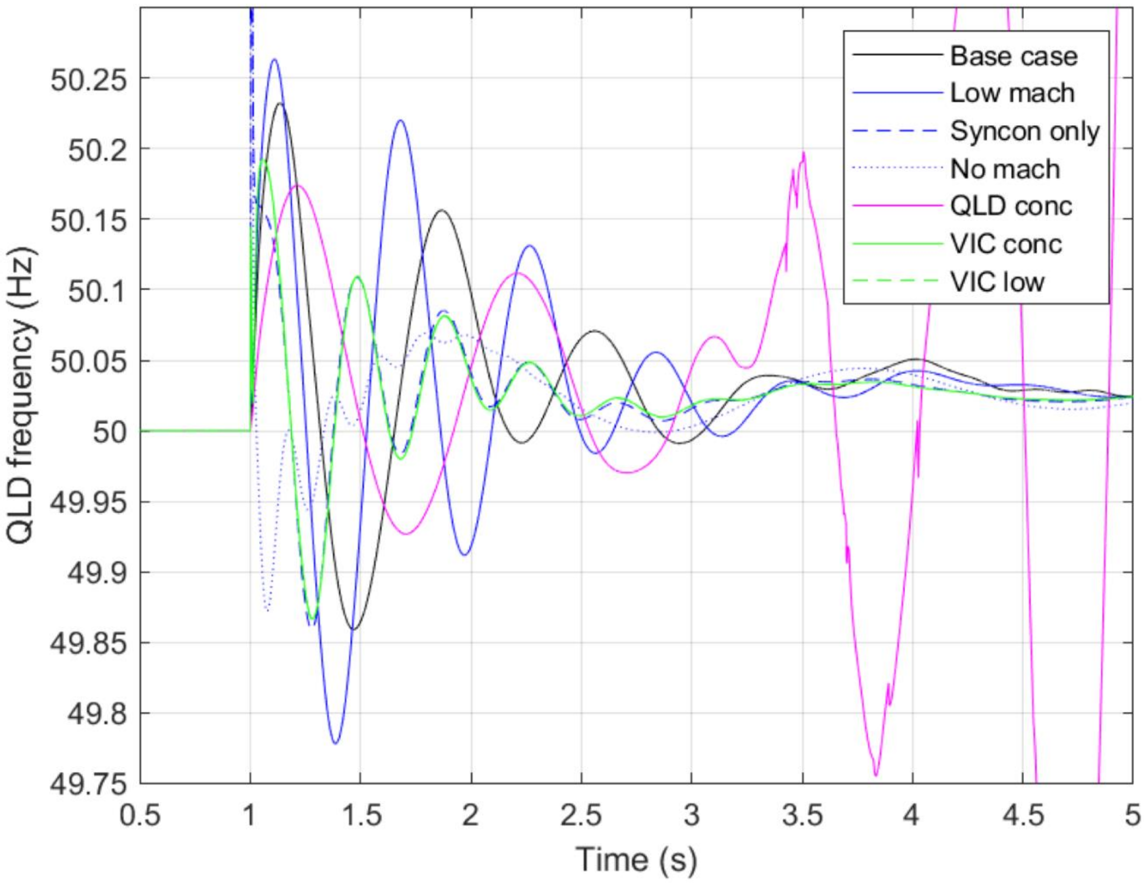


Figure 24 Response of QLD frequency to QLD-NSW separation event

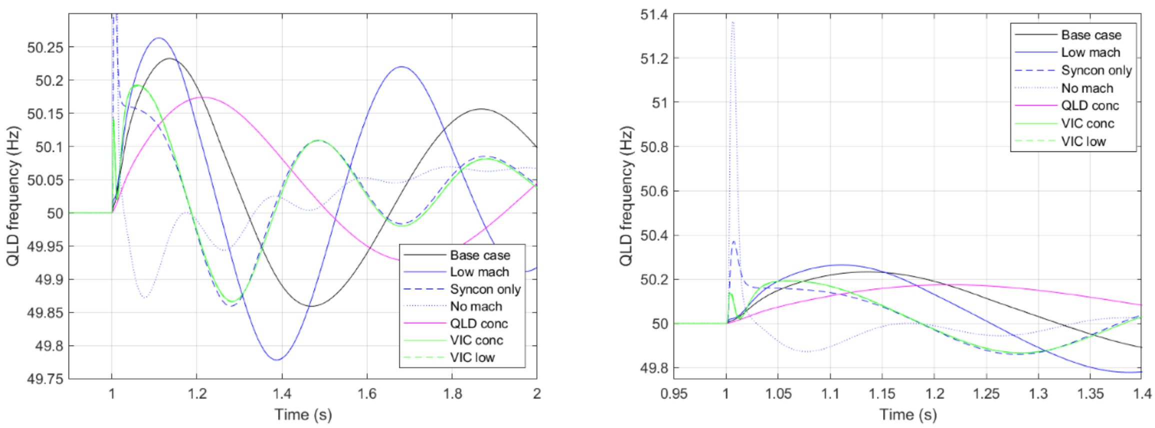


Figure 25 Detail of Figure 24

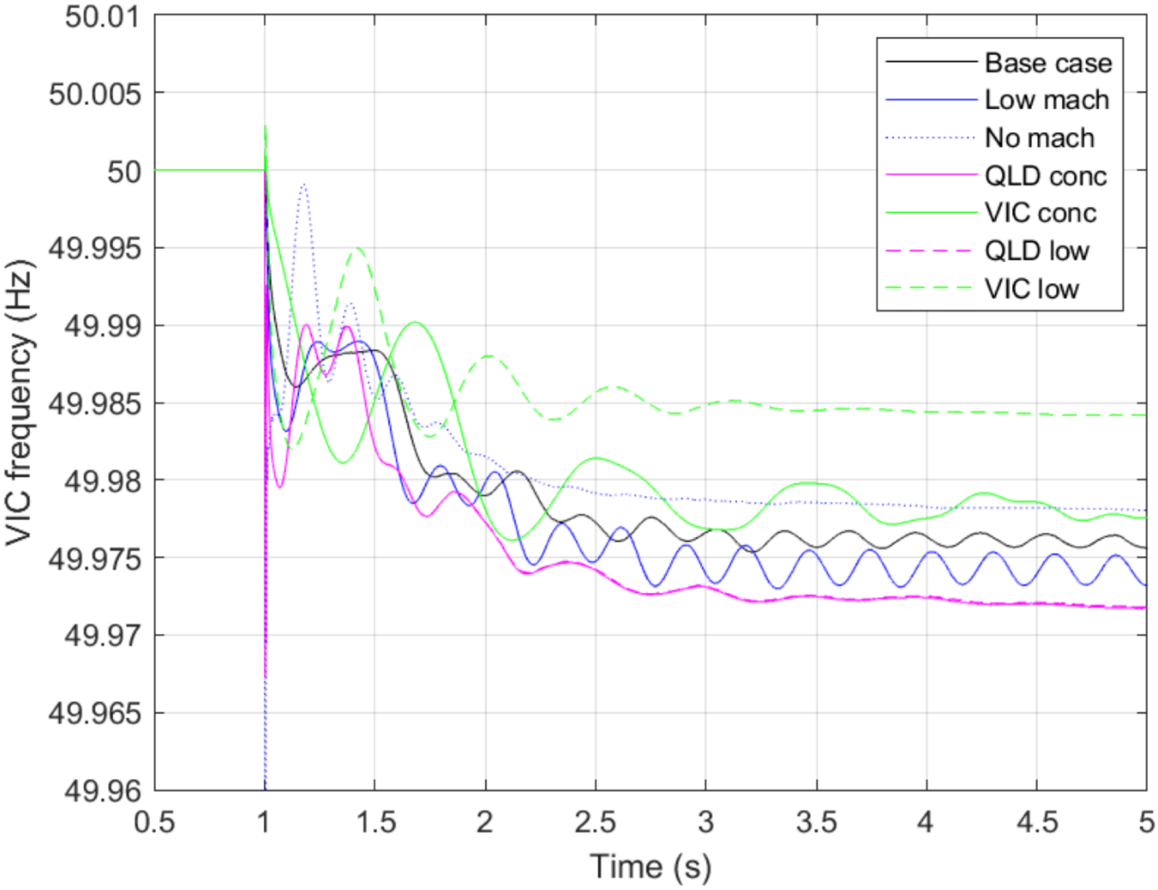


Figure 26 Response of VIC frequency to QLD-NSW separation event

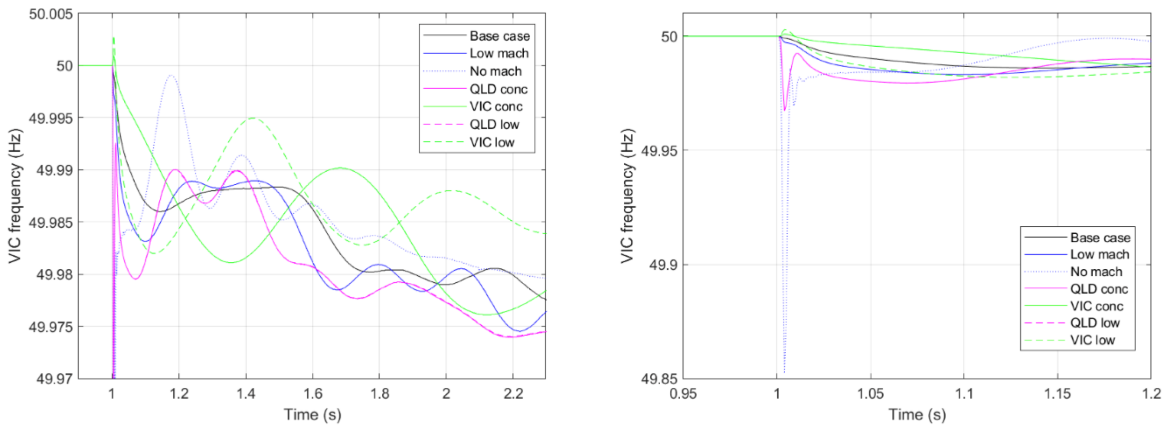


Figure 27 Detail of Figure 26

3.4. Sensitivity Cases

3.4.1. Operation Without GFM Plants

Sensitivity studies were undertaken to compare the behaviour of the system models without the synthetic inertial response contributed by grid-forming IBRs. In these studies, the grid-forming IBRs were replaced with identically-sized grid-following IBRs configured to match other IBRs in the system.

When the grid-forming IBRs are omitted, the system cases are no longer stable for the large disturbances studied. Comparisons are accordingly based on a smaller 100MW generator rejection in the VIC region (which it may be remembered contains synchronous condensers but no synchronous generators in the base case).

Figure 28 compares the response of the VIC frequency to the 100MW generator trip with and without the presence of the grid-forming IBRs. It may be noted that without the grid-forming plant the frequency after the disturbance settles at round 49.96Hz, consistent with a conventional area frequency response characteristic around 2GW to 2.5GW per Hz. Addition of grid-forming plant leads to frequency settling at a higher value albeit still below 50Hz.

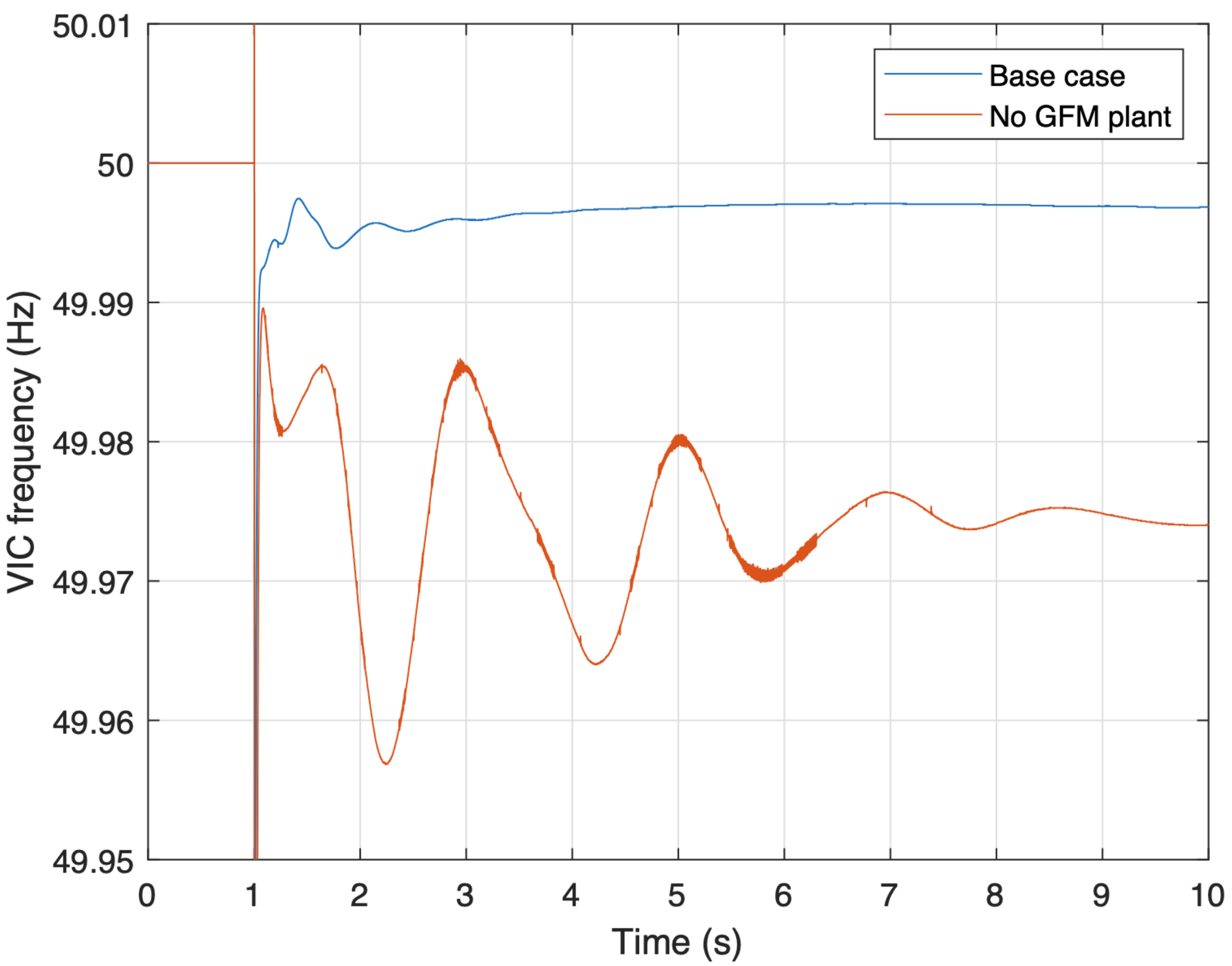


Figure 28 Comparison of base Case 3 for 100MW VIC generator trip with and without GFM plant

Across the developed cases, it is found that only Case 3a, with its overall 50% reduction in synchronous inertia, produces a stable response to this event in the absence of grid-forming plant.

Notably, stable responses cannot be obtained under our study assumptions by increasing synchronous inertia in any one part of the system if it comes at the expense of synchronous inertia in other regions. Of course, it cannot be ruled out that this is a consequence of the greatly simplified nature of the modelling and the control system tuning undertaken for these cases. Accordingly the instability of the developed cases does not necessarily lead to a robust conclusion that concentrating synchronous inertia in regions lacking synthetic inertial response would not aid stability.

Figure 29 and Figure 30 show the response of VIC region frequency in Case 3 and Case 3a with no grid-forming IBR present. Table 12 sums up the key metrics for VIC and QLD frequency and angle deviation for these two cases.

Table 12 Summary metrics for 100MW VIC generator rejection without GFM plant

Case	VIC max RoCoF (Hz/s)	VIC max Δf (Hz)	QLD max RoCoF (Hz/s)	QLD max Δf (Hz)	QLD-SA max Δangle (deg)
3 – base	0.425	0.0380	0.075	0.0181	80.6
3a – low mach	0.475	0.0651	0.225	0.0266	82.3

The metrics in Table 12 continue to support the intuitive conclusion that reducing the synchronous inertia across the system results in greater overall frequency and angle variations, other things being equal.Overall, the results of these sensitivity studies also lead to the conclusion that operation of the system with very low synchronous inertia risks substantially more adverse outcomes when not accompanied by some amount of synthetic inertial response from IBRs that displace synchronous machines. There is support in these studies for a guiding principle that grid-forming capable plant (whether generation or BESS) at a level equivalent to around 10% of installed IBR generation capacity is likely to be of material benefit to the system.

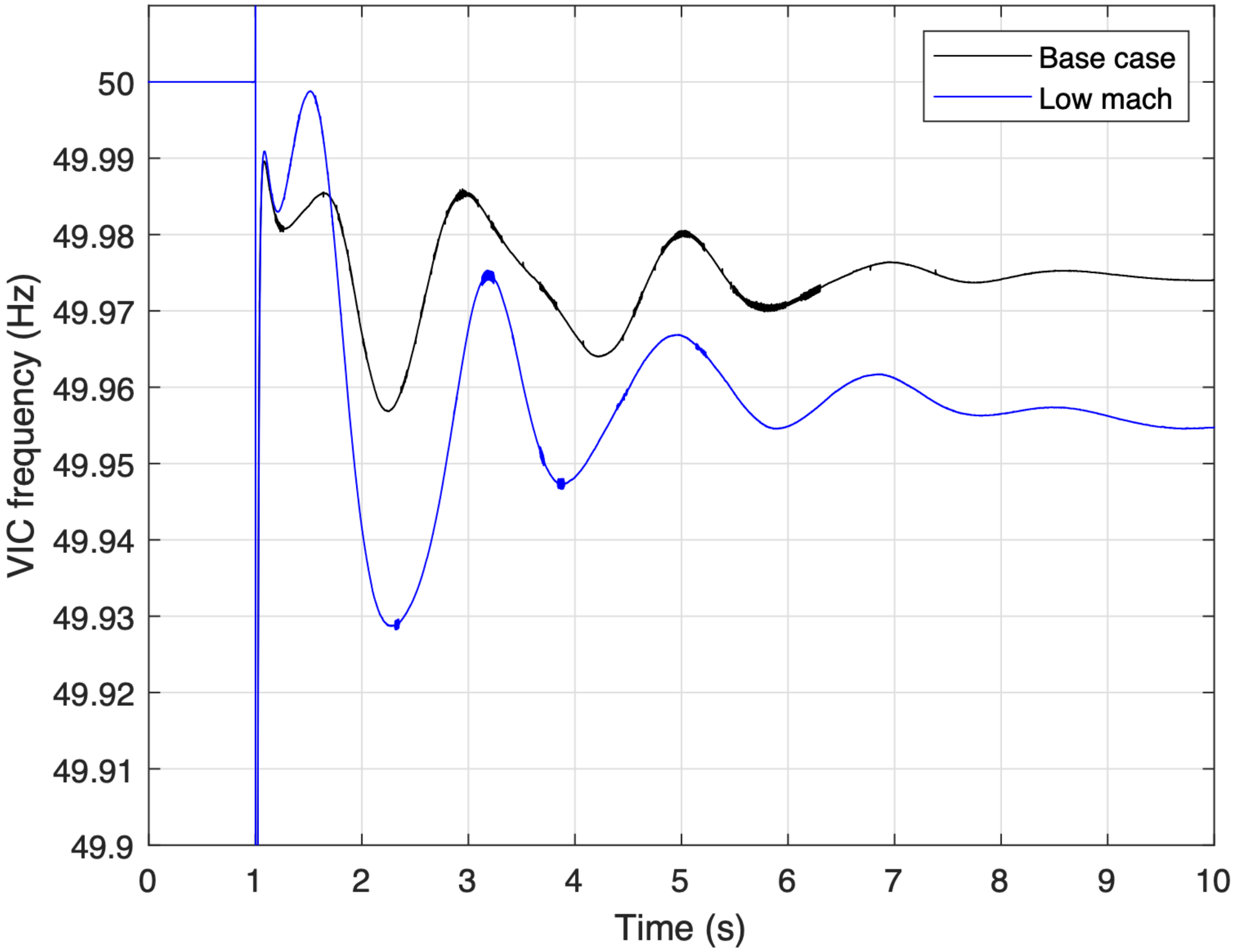


Figure 29 Response of VIC frequency to VIC 100MW generator trip with no GFM plant

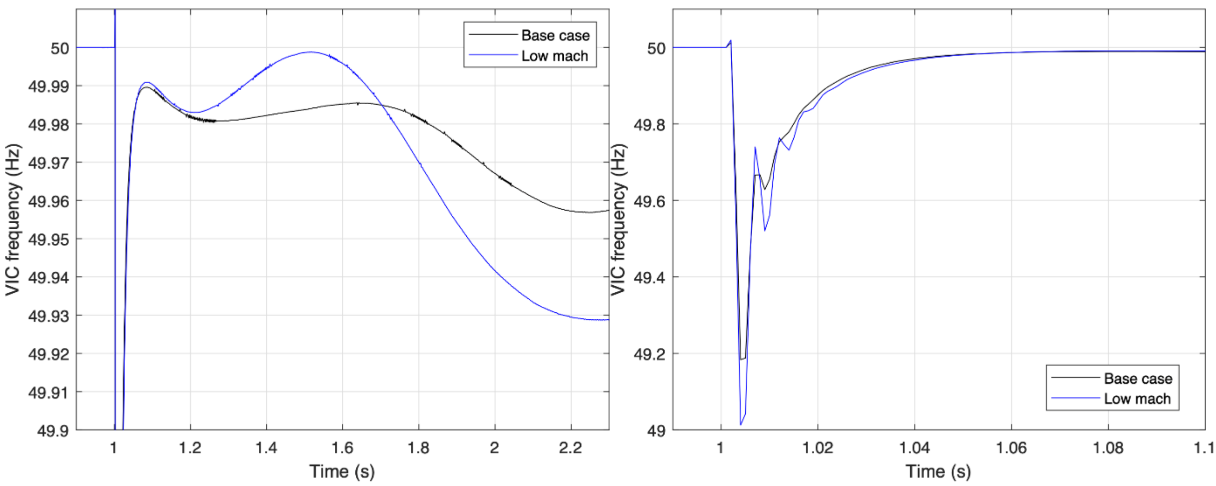


Figure 30 Detail of Figure 29

3.4.2. Separation Event with Additional GFM Plant and Low Synchronous Inertia

A sensitivity study was undertaken re-running the QLD–NSW system separation event with additional grid-forming IBRs located in the QLD and SA regions. This allowed stable results to be generated for Case 3f (QLD concentration, low synchronous generation) in addition to the cases reported in Section 3.3 above. However, Case 3d for QLD generator concentration still gave unstable results similar to those previously reported.

The specific changes made to the base cases were to convert a 1250MVA BESS plant in QLD and a 1000MVA BESS plant in SA from grid-following to grid-forming, at busbars 441 and 521 respectively. (The latter is the same plant converted in Case 3c.) The grid-forming BESS plants were configured identically to the existing grid-forming BESS at bus 321.

Figure 31 and Figure 32 provide the results for the QLD frequency, and Figure 33 and Figure 34 for the VIC frequency for this event in the modified system. Comparison with Figure 26 and Figure 27 confirms that the results for VIC frequency are very similar to the original cases, indicating that the additional GFM plant in SA has only a marginal effect in this scenario. Oscillatory behaviour remains in the VIC frequency traces for several cases indicating some mistuning of frequency damping controls. Meanwhile however, there is a substantial reduction in RoCoF and frequency variation in QLD, particularly for the cases with low and/or geographically concentrated synchronous inertia.

Table 13 provides the summary metrics for these cases with additional GFM plant. There is an overall improvement in the QLD metrics to accompany the qualitative improvement in stability for Case 3f in particular. A slight quantitative improvement in the VIC frequency metrics is also evident as a consequence of the additional GFM plant in SA.

Table 13 Summary metrics for QLD-NSW system separation with additional GFM plant

Case	QLD max RoCoF (Hz/s)	QLD max Δf (Hz)	VIC max RoCoF (Hz/s)	VIC max Δf (Hz)	NSW-SA max Δangle (deg)
3 – base	1.700	0.2014	0.050	0.0164	30.4
3a – low mach	2.000	0.2016	0.100	0.0181	30.4
3b – s'con only	1.275	0.1130	(oscillatory)	0.0445	30.0
3c – no mach	0.750	0.0253	0.300	0.0192	29.5
3d – QLD conc	0.925	0.1569	0.175	0.0186	29.8
3e – VIC conc	1.325	0.1231	0.075	0.0188	30.5
3f – QLD low	1.800	0.1941	0.175	0.0185	29.8
3g – VIC low	1.325	0.1226	0.075	0.0147	30.2

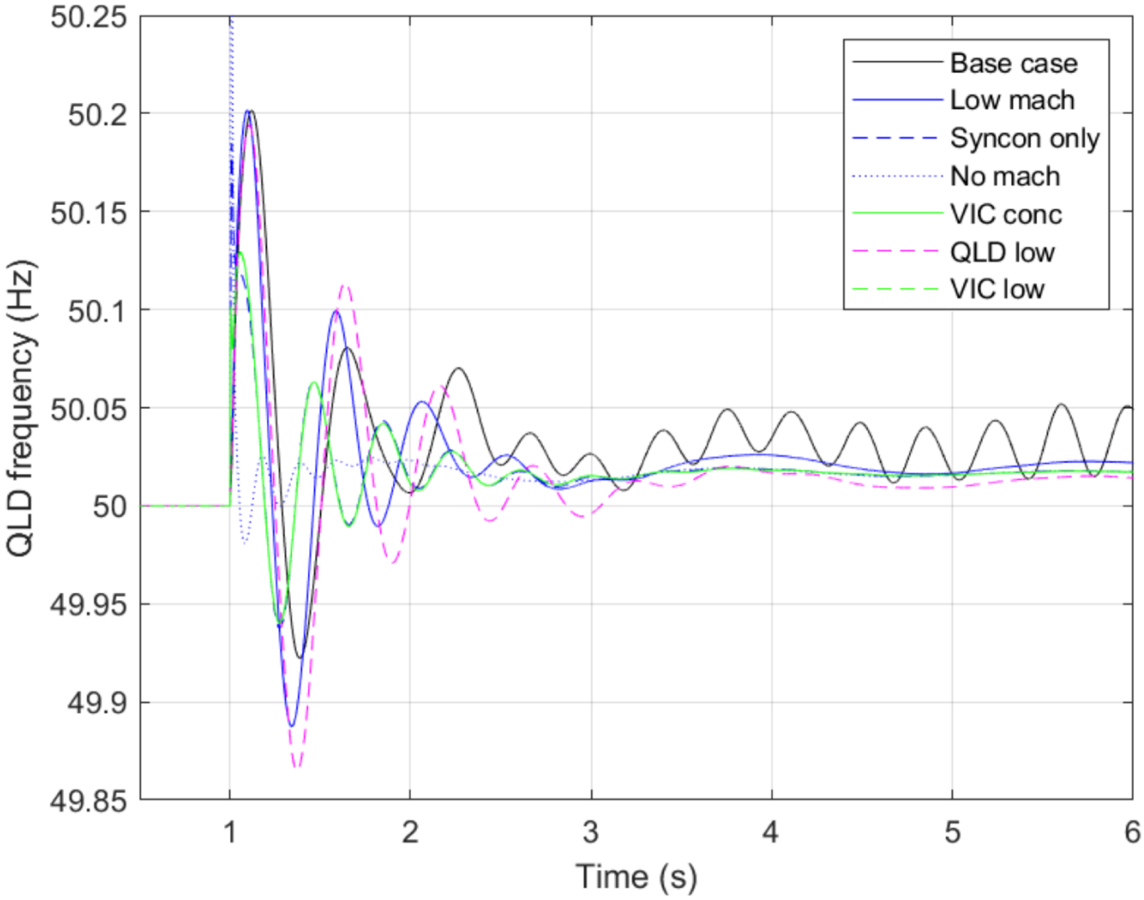


Figure 31 Response of QLD frequency for system separation with additional VIC GFM

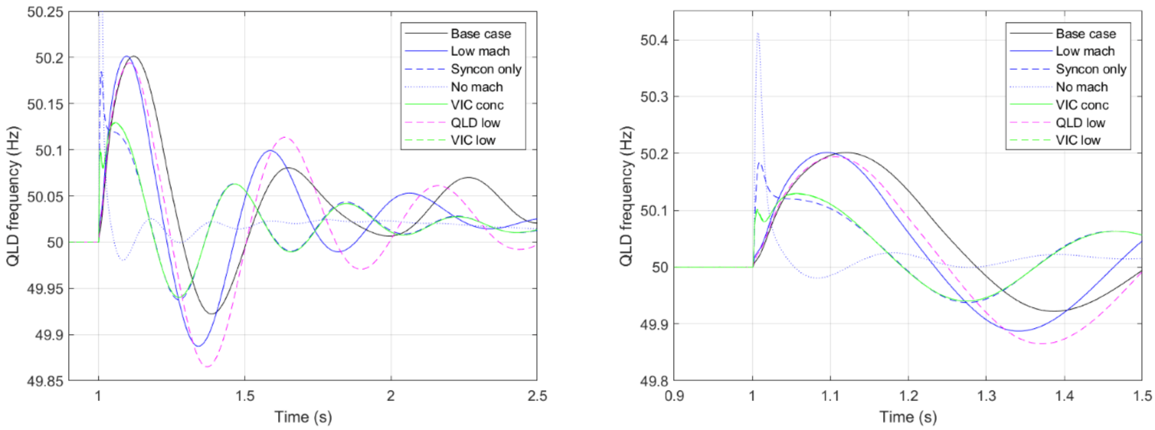


Figure 32 Detail of Figure 31

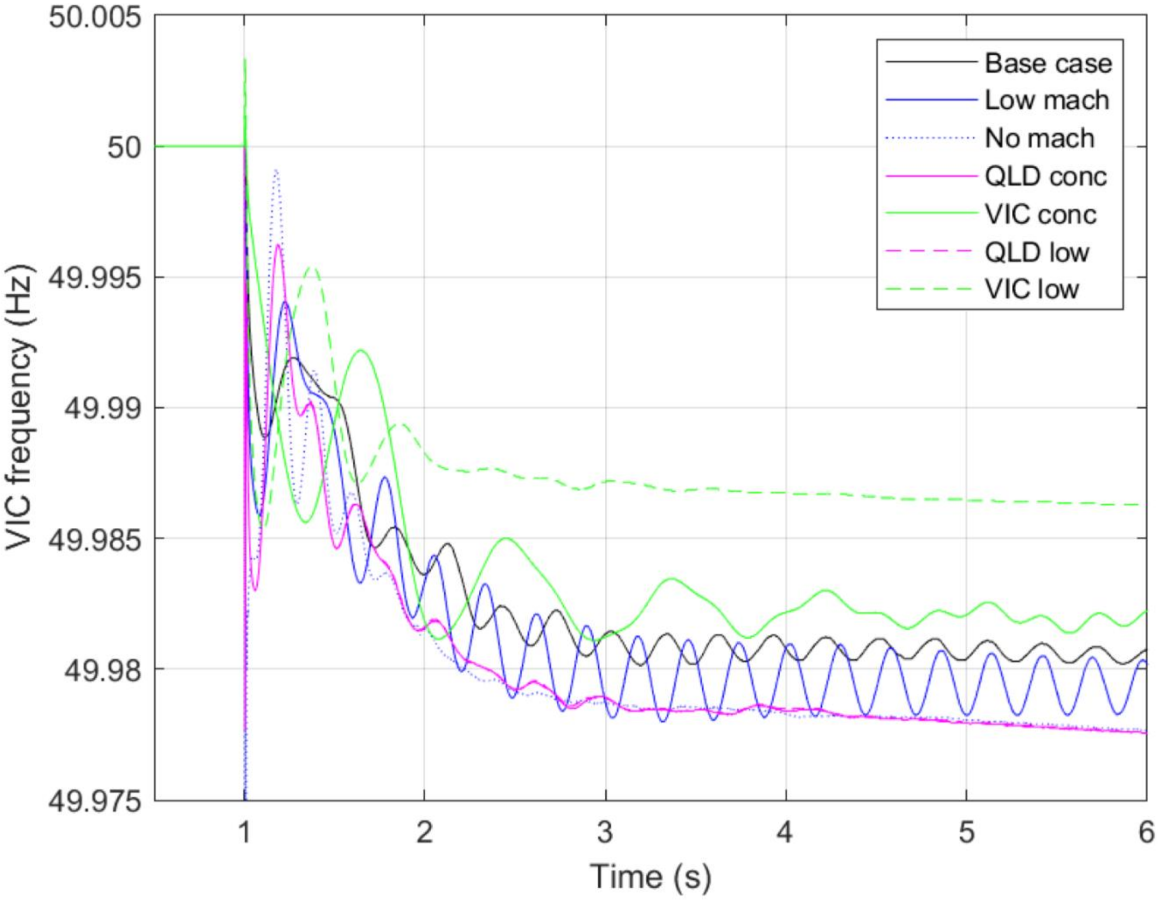


Figure 33 Response of VIC frequency to system separation with additional VIC GFM

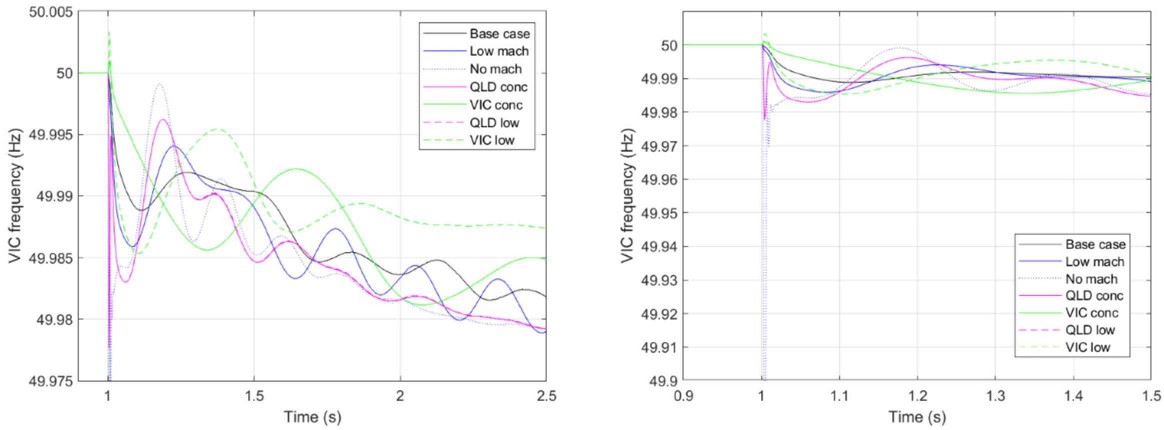


Figure 34 Detail of Figure 33

4. Conclusion

Large-disturbance studies in PSS/E software have been undertaken on a simplified NEM-like system model to investigate frequency and angle stability phenomena under very low levels of synchronous inertia.

These studies are of a speculative and high level nature, and the modelling representative of NEM behaviour in only the broadest terms. A great detail more analysis will be required, considering a much broader set of operating conditions and contingencies in full detail (a necessarily much more time-consuming exercise) before real-world operation of the power system could be considered under the conditions modelled here. The present studies do highlight the value of this further analysis and suggest some promising directions for more investigation in the near term.

Our results here, while not fully definitive in the context of the NEM without further analysis, point to the following broad conclusions.

Geographic distribution of synchronous inertia

Study evidence indicates that the NEM continues to draw substantial benefit from this historical situation, our general conclusion being that 'location matters'. That is, the geographic concentration or spread of synchronous inertia sources has material consequences for regional and global stability of the system. This is the case not only for post-contingent operation but also for intact 'system normal' operation. While results mostly confirmed the intuitively expected inverse relationship between cumulative inertia and large-disturbance performance metrics such as maximum RoCoF and peak frequency deviation, notable exceptions were identified with many attributable to locational factors.

The results for 500MW generator rejection events in the VIC region, in particular, suggest it is unlikely to be technically feasible to concentrate synchronous inertia in a single region (QLD in this case) in the expectation that all regions will benefit from the concentrated inertia source. While the fact that frequency is a system-wide characteristic may intuitively suggest a single location-agnostic 'inertia market' is workable, stability in practice is about much more than sharing a frequency variable with other parts of a system.

The results for 600MW generator rejection events in the QLD region further suggest that a concentration of synchronous inertia in one region may not even be optimal when considering stability in that region alone. Overall, the examples provided show that systems with overly concentrated synchronous inertia can have inferior stability performance relative to those with a broader geographic distribution even when the latter have a lower level of inertia overall.

Low to zero levels of synchronous inertia

The results at this restricted level of modelling indicate it is feasible at a high level to operate the power system with low to zero levels of synchronous inertia if there is a basic level of synthetic inertial response available from grid-forming IBRs. While it was not the purpose of this study to investigate the minimum required size or location of GFM plants or to optimally tune these plants, it has been found that a system with 37,000MVA.s of synthetic inertial response (in round figures) obtained from 10,500MVA of grid-forming IBR capacity was able to operate in a stable manner in the absence of synchronous machines, and withstand a limited range of disturbances without an exhaustive tuning effort.

The study results also indicate a system with zero synchronous inertia may behave in a manner qualitatively different even from one with small but nonzero synchronous inertia, and further investigations on such systems are warranted to understand this behaviour. Thus it is not unlikely that to the extent the zero-machine cases presented here display inferior performance, this could be improved to some degree through more detailed study and control tuning. It remains likely that in the real NEM, a minimum floor level of rotating synchronous inertia will persevere for the foreseeable future.

Studies also reveal a dramatic difference in stability performance between cases with low synchronous inertia supported by a moderate level of synthetic inertial response, and those without such support. In future scenarios with high penetrations of IBRs displacing synchronous machines it may be presumed that at least a small proportion of these will utilise GFM technology; indeed in the NEM this is all but guaranteed under recent rule changes to address system strength. While this should not be interpreted as a target, our results here indicate that a level of GFM plant corresponding to at least 10% of installed IBR generation capacity (where this may be provided either by BESS or generation plant) is sufficient to achieve material system benefits.

In any event, further work will be needed to study in detail the feasibility of operating the real NEM at low to zero levels of inertia and the minimum level of GFM or other technology likely to be needed.

Interaction with other stability phenomena

Inertia characteristics in AC power systems, as defined in this report, are known to have a close technical relationship with system strength characteristics (broadly defined as those system characteristics that govern the level of short-circuit fault current and the sensitivity of local voltage magnitudes to disturbances in power flow). While it was not the purpose here to study this relationship, it is indirectly apparent where certain study cases did not display stable behaviour at all for certain disturbances. A common reason for this on further investigation was failure of voltage stability leading to generating units tripping on over- or under-voltage in a cascading sequence.

Under the assumptions in these studies (including an assumed minimum level of grid-forming plant amongst the rollout of IBRs) the level of synchronous inertia in the base ‘Case 3’ scenario, consistent with the Integrated System Plan ‘step change’ scenario for 2031, was generally robust to these other stability effects. However, it is apparent that any further reduction in synchronous inertia, or changes in assumptions on the distribution of synchronous inertia, can render the system vulnerable to other types of instability in the absence of remedial measures such as additional voltage support, or a higher penetration of grid-forming IBRs. It therefore appears likely that AEMO will need to give closer consideration to the interaction of inertia with other stability characteristics under plausible post-2030 operating conditions for the NEM.

5. References

[1] Australian Energy Market Operator. *Inertia in the NEM explained*, discussion paper, March 2023. Available online via https://aemo.com.au/initiatives/major-programs/engineering-framework/reports-and-resources.

[2] M. Gibbard and D. Vowles. *Simplified 14-generator model of the SE Australian power system*. Revision 3, School of Electrical and Electronic Engineering, University of Adelaide, 30 June 2010.

[3] Vysus Group. *Grid-Forming Battery Inverter Impact Study: Preliminary Report*. Report to Australian Renewable Energy Agency, December 2021.

[4] Australian Energy Market Operator. *2022 Integrated System Plan for the National Electricity Market*. Version 1.0, June 2022.

Appendix: PSS/E Base Case Listings

A.1 Case 3 load flow RAW data listing

```
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   275,'2_BGA330    ', 330.0000,1,   2,   1,   1,1.02832,   2.9504
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   277,'2_WGA330    ', 330.0000,1,   2,   1,   1,1.03386,   3.5771
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```

```
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   282,'1 ',1,   2,   1,  2490.000,   249.000,     0.000,     0.000,     0.000,     0.000,   1,1
   283,'1 ',1,   2,   1,  2760.000,   276.000,     0.000,     0.000,     0.000,     0.000,   1,1
   284,'1 ',1,   2,   1,  2820.000,   282.000,     0.000,     0.000,     0.000,     0.000,   1,1
   286,'1 ',1,   2,   1,  2550.000,   255.000,     0.000,     0.000,     0.000,     0.000,   1,1
   287,'1 ',1,   2,   1,  1800.000,   180.000,     0.000,     0.000,     0.000,     0.000,   1,1
   321,'1 ',1,   3,   1,   170.000,    17.000,     0.000,     0.000,     0.000,     0.000,   1,1
   331,'1 ',1,   3,   1,   283.000,    28.000,     0.000,     0.000,     0.000,     0.000,   1,1
   351,'1 ',1,   3,   1,   870.000,    87.000,     0.000,     0.000,     0.000,     0.000,   1,1
   353,'1 ',1,   3,   1,  1800.000,   180.000,     0.000,     0.000,     0.000,     0.000,   1,1
   354,'1 ',1,   3,   1,   950.000,    95.000,     0.000,     0.000,     0.000,     0.000,   1,1
   362,'1 ',1,   3,   1,    44.000,     4.000,     0.000,     0.000,     0.000,     0.000,   1,1
   363,'1 ',1,   3,   1,    30.000,     3.000,     0.000,     0.000,     0.000,     0.000,   1,1
   371,'1 ',1,   3,   1,  3490.000,   349.000,     0.000,     0.000,     0.000,     0.000,   1,1
   372,'1 ',1,   3,   1,   363.000,    36.000,     0.000,     0.000,     0.000,     0.000,   1,1
   411,'1 ',1,   4,   1,   830.000,    83.000,     0.000,     0.000,     0.000,     0.000,   1,1
   421,'1 ',1,   4,   1,   220.000,    22.000,     0.000,     0.000,     0.000,     0.000,   1,1
   431,'1 ',1,   4,   1,    20.000,     2.000,     0.000,     0.000,     0.000,     0.000,   1,1
   441,'1 ',1,   4,   1,  1550.000,   155.000,     0.000,     0.000,     0.000,     0.000,   1,1
   471,'1 ',1,   4,   1,  1950.000,   195.000,     0.000,     0.000,     0.000,     0.000,   1,1
   472,'1 ',1,   4,   1,  1140.000,   114.000,     0.000,     0.000,     0.000,     0.000,   1,1
   473,'1 ',1,   4,   1,   890.000,    89.000,     0.000,     0.000,     0.000,     0.000,   1,1
   474,'1 ',1,   4,   1,   400.000,    40.000,     0.000,     0.000,     0.000,     0.000,   1,1
   511,'1 ',1,   5,   1,   450.000,    90.000,     0.000,     0.000,     0.000,     0.000,   1,1
   581,'1 ',1,   5,   1,  1500.000,   300.000,     0.000,     0.000,     0.000,     0.000,   1,1
   582,'1 ',1,   5,   1,   350.000,    60.000,     0.000,     0.000,     0.000,     0.000,   1,1
   583,'1 ',1,   5,   1,  1200.000,    60.000,     0.000,     0.000,     0.000,     0.000,   1,1
0 / END OF LOAD DATA, BEGIN FIXED SHUNT DATA
   274,'1 ',1,     0.000,  -160.000
   275,'1 ',1,     0.000,  -160.000
   282,'1 ',1,     0.000,   400.000
   283,'1 ',1,     0.000,   300.000
   473,'1 ',1,     0.000,    30.000
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   474,'1 ',1,     0.000,    60.000
   481,'1 ',1,     0.000,   -30.000
   482,'1 ',1,     0.000,   -60.000
   483,'1 ',1,     0.000,   -60.000
   574,'1 ',1,     0.000,  -120.000
0 / END OF FIXED SHUNT DATA, BEGIN GENERATOR DATA
   201,'B ',     0.000,     0.000,  9999.000, -9999.000,1.03000,     0,  2000.000, 0.00000E+0,
9.99000E+2, 0.00000E+0, 0.00000E+0,1.00000,1,   10.0,  9999.000, -9999.000,   1,1.0000
   201,'I ',     0.000,     0.000,  9999.000, -9999.000,1.03000,     0,  2000.000, 0.00000E+0,
9.99000E+2, 0.00000E+0, 0.00000E+0,1.00000,1,   10.0,  9999.000,     0.000,   1,1.0000
   201,'M ',  1653.426,  -176.035,  9999.000, -9999.000,1.03000,     0,  4000.000, 0.00000E+0,
2.50000E-1, 0.00000E+0, 0.00000E+0,1.00000,1,   10.0,  9999.000,     0.000,   1,1.0000
   201,'Q ',     0.000,     0.000,  9999.000, -9999.000,1.03000,     0,   250.000, 0.00000E+0,
1.52000E-1, 0.00000E+0, 0.00000E+0,1.00000,1,   10.0,  9999.000, -9999.000,   1,1.0000
   211,'B ',     0.000,     0.000,  9999.000, -9999.000,1.02000,     0,  2500.000, 0.00000E+0,
9.99000E+2, 0.00000E+0, 0.00000E+0,1.00000,1,   10.0,  9999.000, -9999.000,   1,1.0000
   211,'I ',  3000.000,   291.899,  9999.000, -9999.000,1.02000,     0,  4000.000, 0.00000E+0,
9.99000E+2, 0.00000E+0, 0.00000E+0,1.00000,1,   10.0,  9999.000,     0.000,   1,1.0000
   211,'M ',   800.000,    77.840,  9999.000, -9999.000,1.02000,     0,  1000.000, 0.00000E+0,
2.10000E-1, 0.00000E+0, 0.00000E+0,1.00000,1,   10.0,  9999.000,     0.000,   1,1.0000
   211,'Q ',     0.000,     0.000,  9999.000, -9999.000,1.02000,     0,   250.000, 0.00000E+0,
1.52000E-1, 0.00000E+0, 0.00000E+0,1.00000,1,   10.0,  9999.000, -9999.000,   1,1.0000
   221,'B ',     0.000,     0.000,  9999.000, -9999.000,1.02000,     0,  2000.000, 0.00000E+0,
2.00000E-1, 0.00000E+0, 0.00000E+0,1.00000,1,   10.0,  9999.000, -9999.000,   1,1.0000
   221,'I ',  2500.000,   440.093,  9999.000, -9999.000,1.02000,     0,  4000.000, 0.00000E+0,
9.99000E+2, 0.00000E+0, 0.00000E+0,1.00000,1,   10.0,  9999.000,     0.000,   1,1.0000
   231,'M ',   900.000,   336.179,  9999.000, -9999.000,1.01000,     0,  1000.000, 0.00000E+0,
2.50000E-1, 0.00000E+0, 0.00000E+0,1.00000,1,  100.0,  9999.000,     0.000,   1,1.0000
   241,'B ',     0.000,     0.000,  9999.000, -9999.000,1.02000,     0,  2000.000, 0.00000E+0,
9.99000E+2, 0.00000E+0, 0.00000E+0,1.00000,1,   10.0,  9999.000, -9999.000,   1,1.0000
   241,'I ',  2000.000,    82.127,  9999.000, -9999.000,1.02000,     0,  4000.000, 0.00000E+0,
9.99000E+2, 0.00000E+0, 0.00000E+0,1.00000,1,   10.0,  9999.000,     0.000,   1,1.0000
   241,'M ',   900.000,    36.957,  9999.000, -9999.000,1.02000,     0,  1000.000, 0.00000E+0,
2.10000E-1, 0.00000E+0, 0.00000E+0,1.00000,1,   10.0,  9999.000,     0.000,   1,1.0000
   266,'B ',     0.000,     0.000,  9999.000, -9999.000,1.03000,     0,  2000.000, 0.00000E+0,
9.99000E+2, 0.00000E+0, 0.00000E+0,1.00000,1,   90.0,  9999.000, -9999.000,   1,1.0000
   266,'I ',  1500.000,    16.878,  9999.000, -9999.000,1.03000,     0,  4000.000, 0.00000E+0,
9.99000E+2, 0.00000E+0, 0.00000E+0,1.00000,1,   90.0,  9999.000,     0.000,   1,1.0000
   281,'B ',     0.000,     0.000,  9999.000, -9999.000,1.03000,     0,  2000.000, 0.00000E+0,
9.99000E+2, 0.00000E+0, 0.00000E+0,1.00000,1,   90.0,  9999.000, -9999.000,   1,1.0000
   281,'I ',  1000.000,   -95.487,  9999.000, -9999.000,1.03000,     0,  4000.000, 0.00000E+0,
9.99000E+2, 0.00000E+0, 0.00000E+0,1.00000,1,   90.0,  9999.000,     0.000,   1,1.0000
   282,'B ',     0.000,     0.000,  9999.000, -9999.000,1.01000,     0,  2500.000, 0.00000E+0,
9.99000E+2, 0.00000E+0, 0.00000E+0,1.00000,1,   90.0,  9999.000, -9999.000,   1,1.0000
   282,'I ',  1000.000,   550.852,  9999.000, -9999.000,1.01000,     0,  4000.000, 0.00000E+0,
9.99000E+2, 0.00000E+0, 0.00000E+0,1.00000,1,   90.0,  9999.000,     0.000,   1,1.0000
   283,'I ',  1000.000,   291.429,  9999.000, -9999.000,1.01500,     0,  4000.000, 0.00000E+0,
9.99000E+2, 0.00000E+0, 0.00000E+0,1.00000,1,  100.0,  9999.000,     0.000,   1,1.0000
   311,'B ',     0.000,     0.000,  9999.000, -9999.000,1.02000,     0,  2000.000, 0.00000E+0,
9.99000E+2, 0.00000E+0, 0.00000E+0,1.00000,1,   10.0,  9999.000, -9999.000,   1,1.0000
   311,'I ',  3000.000,    46.431,  9999.000, -9999.000,1.02000,     0,  4000.000, 0.00000E+0,
9.99000E+2, 0.00000E+0, 0.00000E+0,1.00000,1,   10.0,  9999.000,     0.000,   1,1.0000
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   321,'B ',     0.000,     0.000,  9999.000, -9999.000,1.05000,     0,  2000.000, 0.00000E+0,
2.00000E-1, 0.00000E+0, 0.00000E+0,1.00000,1,   90.0,  9999.000, -9999.000,   1,1.0000
   321,'I ',   639.900,   -10.277,  9999.000, -9999.000,1.05000,     0,  4000.000, 0.00000E+0,
9.99000E+2, 0.00000E+0, 0.00000E+0,1.00000,1,   90.0,  9999.000,     0.000,   1,1.0000
   351,'B ',     0.000,     0.000,  9999.000, -9999.000,1.02000,     0,  2000.000, 0.00000E+0,
9.99000E+2, 0.00000E+0, 0.00000E+0,1.00000,1,   90.0,  9999.000, -9999.000,   1,1.0000
   351,'I ',   500.000,   700.000,  9999.000, -9999.000,1.02000,     0,  3000.000, 0.00000E+0,
9.99000E+2, 0.00000E+0, 0.00000E+0,1.00000,1,   90.0,  9999.000,     0.000,   1,1.0000
   351,'J ',   500.000,    45.769,  9999.000, -9999.000,1.02000,     0,  1000.000, 0.00000E+0,
9.99000E+2, 0.00000E+0, 0.00000E+0,1.00000,1,   10.0,  9999.000,     0.000,   1,1.0000
   362,'B ',     0.000,     0.000,  9999.000, -9999.000,1.01000,     0,  2000.000, 0.00000E+0,
9.99000E+2, 0.00000E+0, 0.00000E+0,1.00000,1,   90.0,  9999.000, -9999.000,   1,1.0000
   362,'I ',   500.000,   615.546,  9999.000, -9999.000,1.01000,     0,  4000.000, 0.00000E+0,
9.99000E+2, 0.00000E+0, 0.00000E+0,1.00000,1,   90.0,  9999.000,     0.000,   1,1.0000
   363,'B ',     0.000,    94.307,  9999.000, -9999.000,1.02500,     0,  2000.000, 0.00000E+0,
9.99000E+2, 0.00000E+0, 0.00000E+0,1.00000,1,   90.0,  9999.000, -9999.000,   1,1.0000
   363,'I ',     0.000,    94.307,  9999.000, -9999.000,1.02500,     0,  2000.000, 0.00000E+0,
9.99000E+2, 0.00000E+0, 0.00000E+0,1.00000,1,   90.0,  9999.000,     0.000,   1,1.0000
   365,'B ',     0.000,     0.000,  9999.000, -9999.000,1.03000,     0,  1500.000, 0.00000E+0,
9.99000E+2, 0.00000E+0, 0.00000E+0,1.00000,1,   10.0,  9999.000, -9999.000,   1,1.0000
   365,'I ',   500.000,    92.978,  9999.000, -9999.000,1.03000,     0,  4000.000, 0.00000E+0,
9.99000E+2, 0.00000E+0, 0.00000E+0,1.00000,1,   10.0,  9999.000,     0.000,   1,1.0000
   365,'Q ',     0.000,     0.000,  9999.000, -9999.000,1.03000,     0,   250.000, 0.00000E+0,
1.52000E-1, 0.00000E+0, 0.00000E+0,1.00000,1,   10.0,  9999.000, -9999.000,   1,1.0000
   366,'B ',     0.000,     0.000,  9999.000, -9999.000,1.03500,     0,  1500.000, 0.00000E+0,
9.99000E+2, 0.00000E+0, 0.00000E+0,1.00000,1,   90.0,  9999.000, -9999.000,   1,1.0000
   366,'I ',  1000.000,    58.652,  9999.000, -9999.000,1.03500,     0,  4000.000, 0.00000E+0,
9.99000E+2, 0.00000E+0, 0.00000E+0,1.00000,1,   90.0,  9999.000,     0.000,   1,1.0000
   371,'B ',     0.000,     0.000,  9999.000, -9999.000,1.04000,     0,  2000.000, 0.00000E+0,
9.99000E+2, 0.00000E+0, 0.00000E+0,1.00000,1,  100.0,  9999.000, -9999.000,   1,1.0000
   371,'I ',  1000.000,    42.991,  9999.000, -9999.000,1.04000,     0,  4000.000, 0.00000E+0,
9.99000E+2, 0.00000E+0, 0.00000E+0,1.00000,1,  100.0,  9999.000,     0.000,   1,1.0000
   411,'B ',     0.000,     0.000,  9999.000, -9999.000,1.02000,     0,  1250.000, 0.00000E+0,
9.99000E+2, 0.00000E+0, 0.00000E+0,1.00000,1,   50.0,  9999.000, -9999.000,   1,1.0000
   411,'M ',  1200.000,   416.932,  9999.000, -9999.000,1.02000,     0,  1500.000, 0.00000E+0,
2.50000E-1, 0.00000E+0, 0.00000E+0,1.00000,1,   50.0,  9999.000,     0.000,   1,1.0000
   421,'B ',     0.000,     0.000,  9999.000, -9999.000,1.02000,     0,  1250.000, 0.00000E+0,
9.99000E+2, 0.00000E+0, 0.00000E+0,1.00000,1,   70.0,  9999.000, -9999.000,   1,1.0000
   421,'I ',  1200.000,   -34.544,  9999.000, -9999.000,1.02000,     0,  4000.000, 0.00000E+0,
9.99000E+2, 0.00000E+0, 0.00000E+0,1.00000,1,   70.0,  9999.000,     0.000,   1,1.0000
   431,'B ',     0.000,     0.000,  9999.000, -9999.000,1.04000,     0,  1250.000, 0.00000E+0,
9.99000E+2, 0.00000E+0, 0.00000E+0,1.00000,1,   30.0,  9999.000, -9999.000,   1,1.0000
   431,'I ',     0.000,     0.000,  9999.000, -9999.000,1.04000,     0,  4000.000, 0.00000E+0,
2.00000E-1, 0.00000E+0, 0.00000E+0,1.00000,1,   30.0,  9999.000,     0.000,   1,1.0000
   431,'M ',  1200.000,    79.888,  9999.000, -9999.000,1.04000,     0,  1500.000, 0.00000E+0,
2.50000E-1, 0.00000E+0, 0.00000E+0,1.00000,1,   30.0,  9999.000,     0.000,   1,1.0000
   441,'B ',     0.000,     0.000,  9999.000, -9999.000,1.02000,     0,  1250.000, 0.00000E+0,
9.99000E+2, 0.00000E+0, 0.00000E+0,1.00000,1,   70.0,  9999.000, -9999.000,   1,1.0000
   441,'M ',  1600.800,     1.263,  9999.000, -9999.000,1.02000,     0,  2000.000, 0.00000E+0,
2.40000E-1, 0.00000E+0, 0.00000E+0,1.00000,1,   70.0,  9999.000,     0.000,   1,1.0000
   471,'B ',     0.000,   170.290,  9999.000, -9999.000,0.99000,     0,  1250.000, 0.00000E+0,
9.99000E+2, 0.00000E+0, 0.00000E+0,1.00000,1,   10.0,  9999.000, -9999.000,   1,1.0000
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   471,'Q ',     0.000,    34.058,  9999.000, -9999.000,0.99000,     0,   250.000, 0.00000E+0,
9.99000E+2, 0.00000E+0, 0.00000E+0,1.00000,1,   10.0,  9999.000, -9999.000,   1,1.0000
   472,'B ',     0.000,     0.000,  9999.000, -9999.000,1.03500,     0,  1250.000, 0.00000E+0,
9.99000E+2, 0.00000E+0, 0.00000E+0,1.00000,1,   70.0,  9999.000, -9999.000,   1,1.0000
   472,'I ',   500.000,    92.746,  9999.000, -9999.000,1.03500,     0,  4000.000, 0.00000E+0,
9.99000E+2, 0.00000E+0, 0.00000E+0,1.00000,1,   70.0,  9999.000,     0.000,   1,1.0000
   474,'B ',     0.000,     0.000,  9999.000, -9999.000,0.98500,     0,  1250.000, 0.00000E+0,
9.99000E+2, 0.00000E+0, 0.00000E+0,1.00000,1,   70.0,  9999.000, -9999.000,   1,1.0000
   474,'I ',  1000.000,  -127.064,  9999.000, -9999.000,0.98500,     0,  4000.000, 0.00000E+0,
9.99000E+2, 0.00000E+0, 0.00000E+0,1.00000,1,   70.0,  9999.000,     0.000,   1,1.0000
   475,'B ',     0.000,     0.000,  9999.000, -9999.000,1.04000,     0,  1250.000, 0.00000E+0,
9.99000E+2, 0.00000E+0, 0.00000E+0,1.00000,1,   10.0,  9999.000, -9999.000,   1,1.0000
   475,'I ',   400.000,     2.969,  9999.000, -9999.000,1.04000,     0,  3000.000, 0.00000E+0,
9.99000E+2, 0.00000E+0, 0.00000E+0,1.00000,1,   10.0,  9999.000,     0.000,   1,1.0000
   475,'J ',   600.000,     0.000,  9999.000, -9999.000,1.04000,     0,  1000.000, 0.00000E+0,
9.99000E+2, 0.00000E+0, 0.00000E+0,1.00000,1,   10.0,  9999.000,     0.000,   1,1.0000
   475,'Q ',     0.000,     0.000,  9999.000, -9999.000,1.04000,     0,   125.000, 0.00000E+0,
1.52000E-1, 0.00000E+0, 0.00000E+0,1.00000,1,   10.0,  9999.000, -9999.000,   1,1.0000
   511,'I ',  1000.000,  -342.768,  9999.000, -9999.000,1.05000,     0,  2500.000, 0.00000E+0,
9.99000E+2, 0.00000E+0, 0.00000E+0,1.00000,1,   10.0,  9999.000,     0.000,   1,1.0000
   511,'Q ',     0.000,     0.000,  9999.000, -9999.000,1.05000,     0,   125.000, 0.00000E+0,
1.52000E-1, 0.00000E+0, 0.00000E+0,1.00000,1,   10.0,  9999.000, -9999.000,   1,1.0000
   521,'B ',     0.000,     0.000,  9999.000, -9999.000,1.00000,     0,  1000.000, 0.00000E+0,
9.99000E+2, 0.00000E+0, 0.00000E+0,1.00000,1,   70.0,  9999.000, -9999.000,   1,1.0000
   521,'I ',   600.000,   134.969,  9999.000, -9999.000,1.00000,     0,  2500.000, 0.00000E+0,
9.99000E+2, 0.00000E+0, 0.00000E+0,1.00000,1,   70.0,  9999.000,     0.000,   1,1.0000
   531,'B ',     0.000,     0.000,  9999.000, -9999.000,1.00000,     0,  1000.000, 0.00000E+0,
9.99000E+2, 0.00000E+0, 0.00000E+0,1.00000,1,   70.0,  9999.000, -9999.000,   1,1.0000
   531,'I ',   436.000,   146.339,  9999.000, -9999.000,1.00000,     0,  2500.000, 0.00000E+0,
9.99000E+2, 0.00000E+0, 0.00000E+0,1.00000,1,   70.0,  9999.000,     0.000,   1,1.0000
   581,'B ',     0.000,    54.251,  9999.000, -9999.000,0.99000,     0,  1000.000, 0.00000E+0,
9.99000E+2, 0.00000E+0, 0.00000E+0,1.00000,1,   10.0,  9999.000, -9999.000,   1,1.0000
   581,'Q ',     0.000,    13.563,  9999.000, -9999.000,0.99000,     0,   250.000, 0.00000E+0,
1.35000E-1, 0.00000E+0, 0.00000E+0,1.00000,1,   10.0,  9999.000, -9999.000,   1,1.0000
   582,'B ',     0.000,    24.424,  9999.000, -9999.000,1.02000,     0,  1000.000, 0.00000E+0,
9.99000E+2, 0.00000E+0, 0.00000E+0,1.00000,1,  100.0,  9999.000, -9999.000,   1,1.0000
   583,'B ',     0.000,   351.191,  9999.000, -9999.000,0.98000,     0,  1000.000, 0.00000E+0,
9.99000E+2, 0.00000E+0, 0.00000E+0,1.00000,1,   50.0,  9999.000, -9999.000,   1,1.0000
   584,'I ',  1000.000,  -280.708,  9999.000, -9999.000,1.05000,     0,  2500.000, 0.00000E+0,
9.99000E+2, 0.00000E+0, 0.00000E+0,1.00000,1,   10.0,  9999.000,     0.000,   1,1.0000
0 / END OF GENERATOR DATA, BEGIN BRANCH DATA
   201,    287,'1 ', 8.40000E-3, 6.67000E-2,    0.81700,     0.00,     0.00,     0.00,  0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   201,    287,'2 ', 8.40000E-3, 6.67000E-2,    0.81700,     0.00,     0.00,     0.00,  0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   201,    287,'3 ', 7.80000E-3, 6.20000E-2,    0.76000,     0.00,     0.00,     0.00,  0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   201,    287,'4 ', 7.80000E-3, 6.20000E-2,    0.76000,     0.00,     0.00,     0.00,  0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   201,    331,'1 ', 4.50000E-3, 3.56000E-2,    0.43700,     0.00,     0.00,     0.00,  0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
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   201,    331,'2 ', 4.50000E-3, 3.56000E-2,    0.43700,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   201,    331,'3 ', 1.09000E-2, 8.68000E-2,    0.76000,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   211,    241,'1 ', 6.60000E-3, 5.27000E-2,    0.64600,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   211,    241,'2 ', 6.60000E-3, 5.27000E-2,    0.64600,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   211,    281,'1 ', 9.60000E-3, 7.60000E-2,    0.93100,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,2,   0.00,   1,1.0000
   211,    281,'2 ', 9.60000E-3, 7.60000E-2,    0.93100,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,2,   0.00,   1,1.0000
   211,    281,'3 ', 9.60000E-3, 7.60000E-2,    0.93100,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,2,   0.00,   1,1.0000
   211,    282,'1 ', 6.60000E-3, 5.27000E-2,    0.64600,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   211,    282,'2 ', 6.60000E-3, 5.27000E-2,    0.64600,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   211,    284,'1 ', 4.50000E-3, 3.56000E-2,    0.43700,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   211,    284,'2 ', 4.50000E-3, 3.56000E-2,    0.43700,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   221,    282,'1 ', 4.50000E-3, 3.56000E-2,    0.43700,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   221,    284,'1 ', 8.00000E-4, 6.20000E-3,    0.07600,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,2,   0.00,   1,1.0000
   221,    284,'2 ', 8.00000E-4, 6.20000E-3,    0.07600,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,2,   0.00,   1,1.0000
   231,    284,'1 ', 1.80000E-3, 1.40000E-2,    0.17100,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,2,   0.00,   1,1.0000
   231,    284,'2 ', 1.80000E-3, 1.40000E-2,    0.17100,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,2,   0.00,   1,1.0000
   231,    286,'1 ', 3.10000E-3, 2.48000E-2,    0.30400,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   231,    286,'2 ', 3.10000E-3, 2.48000E-2,    0.30400,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   231,    286,'3 ', 3.10000E-3, 2.48000E-2,    0.30400,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   241,    283,'1 ', 5.10000E-3, 4.03000E-2,    0.49400,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   241,    283,'2 ', 5.10000E-3, 4.03000E-2,    0.49400,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   241,    287,'1 ', 7.20000E-3, 5.74000E-2,    0.70300,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   241,    287,'2 ', 7.20000E-3, 5.74000E-2,    0.70300,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   251,    252,'1 ', 1.00000E-3, 1.45000E-2,    1.54000,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,2,   0.00,   1,1.0000
   251,    252,'2 ', 1.00000E-3, 1.45000E-2,    1.54000,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,2,   0.00,   1,1.0000
   266,    363,'1 ', 4.20000E-2, 1.78000E-1,    0.48600,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
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   266,    363,'2 ', 4.20000E-2, 1.78000E-1,    0.48600,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   266,    365,'1 ', 4.20000E-2, 1.78000E-1,    0.48600,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   274,    574,'1 ', 1.31790E-2, 9.50170E-2,    1.32374,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,2,   0.00,   1,1.0000
   274,    574,'2 ', 1.31790E-2, 9.50170E-2,    1.32374,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,2,   0.00,   1,1.0000
   275,    277,'1 ', 1.79500E-2, 1.45900E-2,    2.31969,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,2,   0.00,   1,1.0000
   275,    277,'2 ', 1.78600E-2, 1.46000E-2,    2.31969,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,2,   0.00,   1,1.0000
   276,    277,'1 ', 6.00000E-3, 4.70000E-2,    0.57300,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   276,    277,'2 ', 6.00000E-3, 4.70000E-2,    0.57300,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   277,    287,'1 ', 6.00000E-3, 4.90000E-2,    0.58000,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   277,    287,'2 ', 6.00000E-3, 4.90000E-2,    0.58000,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   277,    331,'1 ', 7.00000E-3, 5.60000E-2,    0.69600,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   281,    483,'1 ', 3.70000E-3, 4.60000E-2,    0.73000,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   281,    483,'2 ', 3.70000E-3, 4.60000E-2,    0.73000,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   282,    286,'1 ', 1.40000E-3, 1.08000E-2,    0.13300,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,2,   0.00,   1,1.0000
   282,    286,'2 ', 1.40000E-3, 1.08000E-2,    0.13300,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,2,   0.00,   1,1.0000
   282,    287,'1 ', 7.00000E-3, 5.58000E-2,    0.68400,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   282,    287,'2 ', 7.00000E-3, 5.58000E-2,    0.68400,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   283,    285,'1 ', 1.00000E-3, 7.70000E-3,    0.09500,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,2,   0.00,   1,1.0000
   283,    287,'1 ', 5.10000E-3, 4.03000E-2,    0.49400,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   285,    286,'1 ', 1.90000E-3, 1.55000E-2,    0.19000,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,2,   0.00,   1,1.0000
   285,    287,'1 ', 4.90000E-3, 3.88000E-2,    0.47500,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   311,    352,'1 ', 1.10000E-3, 1.60000E-2,    1.70000,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   311,    352,'2 ', 1.10000E-3, 1.60000E-2,    1.70000,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   311,    355,'1 ', 1.00000E-3, 1.40000E-2,    1.48000,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   321,    371,'1 ', 2.00000E-3, 1.50000E-2,    0.90000,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   331,    332,'1 ', 9.00000E-3, 7.13000E-2,    0.87400,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
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   331,    332,'2 ', 9.00000E-3, 7.13000E-2,    0.87400,     0.00,     0.00,     0.00, 0.00000,
0.00000, 0.00000, 0.00000,1,1,   0.00,   1,1.0000
   332,    333,'1 ', 0.00000E+0,-3.37000E-2,    0.00000,     0.00,     0.00,     0.00, 0.00000,
0.00000, 0.00000, 0.00000,1,1,   0.00,   1,1.0000
   332,    333,'2 ', 0.00000E+0,-3.37000E-2,    0.00000,     0.00,     0.00,     0.00, 0.00000,
0.00000, 0.00000, 0.00000,1,1,   0.00,   1,1.0000
   351,    352,'1 ', 3.00000E-4, 4.50000E-3,    0.44700,     0.00,     0.00,     0.00, 0.00000,
0.00000, 0.00000, 0.00000,1,2,   0.00,   1,1.0000
   351,    352,'2 ', 3.00000E-4, 4.50000E-3,    0.44700,     0.00,     0.00,     0.00, 0.00000,
0.00000, 0.00000, 0.00000,1,2,   0.00,   1,1.0000
   351,    353,'1 ', 1.00000E-4, 1.20000E-3,    0.12700,     0.00,     0.00,     0.00, 0.00000,
0.00000, 0.00000, 0.00000,1,2,   0.00,   1,1.0000
   351,    354,'1 ', 2.30000E-3, 3.25000E-2,    3.44500,     0.00,     0.00,     0.00, 0.00000,
0.00000, 0.00000, 0.00000,1,1,   0.00,   1,1.0000
   351,    354,'2 ', 2.30000E-3, 3.25000E-2,    3.44500,     0.00,     0.00,     0.00, 0.00000,
0.00000, 0.00000, 0.00000,1,1,   0.00,   1,1.0000
   352,    353,'1 ', 2.00000E-4, 3.00000E-3,    0.32000,     0.00,     0.00,     0.00, 0.00000,
0.00000, 0.00000, 0.00000,1,1,   0.00,   1,1.0000
   352,    355,'1 ', 3.00000E-4, 4.00000E-3,    0.42400,     0.00,     0.00,     0.00, 0.00000,
0.00000, 0.00000, 0.00000,1,2,   0.00,   1,1.0000
   361,    362,'1 ', 4.00000E-4, 2.00000E-2,    0.32200,     0.00,     0.00,     0.00, 0.00000,
0.00000, 0.00000, 0.00000,1,1,   0.00,   1,1.0000
   361,    362,'2 ', 4.00000E-4, 2.00000E-2,    0.32200,     0.00,     0.00,     0.00, 0.00000,
0.00000, 0.00000, 0.00000,1,1,   0.00,   1,1.0000
   362,    363,'1 ', 1.30000E-2, 7.90000E-2,    0.13300,     0.00,     0.00,     0.00, 0.00000,
0.00000, 0.00000, 0.00000,1,1,   0.00,   1,1.0000
   362,    363,'2 ', 1.30000E-2, 7.90000E-2,    0.13300,     0.00,     0.00,     0.00, 0.00000,
0.00000, 0.00000, 0.00000,1,1,   0.00,   1,1.0000
   362,    366,'1 ', 2.50000E-2, 1.10000E-1,    0.33600,     0.00,     0.00,     0.00, 0.00000,
0.00000, 0.00000, 0.00000,1,1,   0.00,   1,1.0000
   362,    366,'2 ', 2.50000E-2, 1.10000E-1,    0.33600,     0.00,     0.00,     0.00, 0.00000,
0.00000, 0.00000, 0.00000,1,1,   0.00,   1,1.0000
   363,    364,'1 ', 1.40000E-2, 6.80000E-2,    0.59100,     0.00,     0.00,     0.00, 0.00000,
0.00000, 0.00000, 0.00000,1,1,   0.00,   1,1.0000
   363,    365,'1 ', 5.20000E-2, 2.10000E-1,    0.65600,     0.00,     0.00,     0.00, 0.00000,
0.00000, 0.00000, 0.00000,1,1,   0.00,   1,1.0000
   365,    366,'1 ', 4.00000E-2, 1.80000E-1,    0.50000,     0.00,     0.00,     0.00, 0.00000,
0.00000, 0.00000, 0.00000,1,1,   0.00,   1,1.0000
   371,    372,'1 ', 5.00000E-4, 5.00000E-3,    0.52000,     0.00,     0.00,     0.00, 0.00000,
0.00000, 0.00000, 0.00000,1,1,   0.00,   1,1.0000
   381,    582,'1 ', 7.00000E-3, 5.00000E-2,    0.19000,     0.00,     0.00,     0.00, 0.00000,
0.00000, 0.00000, 0.00000,1,1,   0.00,   1,1.0000
   381,    582,'2 ', 7.00000E-3, 5.00000E-2,    0.19000,     0.00,     0.00,     0.00, 0.00000,
0.00000, 0.00000, 0.00000,1,1,   0.00,   1,1.0000
   411,    421,'1 ', 1.10000E-2, 1.28000E-1,    1.01000,     0.00,     0.00,     0.00, 0.00000,
0.00000, 0.00000, 0.00000,1,2,   0.00,   1,1.0000
   411,    421,'2 ', 1.10000E-2, 1.28000E-1,    1.01000,     0.00,     0.00,     0.00, 0.00000,
0.00000, 0.00000, 0.00000,1,2,   0.00,   1,1.0000
   411,    441,'1 ', 1.60000E-2, 1.80000E-1,    1.20000,     0.00,     0.00,     0.00, 0.00000,
0.00000, 0.00000, 0.00000,1,2,   0.00,   1,1.0000
   411,    441,'2 ', 1.60000E-2, 1.80000E-1,    1.20000,     0.00,     0.00,     0.00, 0.00000,
0.00000, 0.00000, 0.00000,1,2,   0.00,   1,1.0000
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   411,    471,'1 ', 4.30000E-3, 5.32000E-2,    0.42700,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   411,    471,'2 ', 4.30000E-3, 5.32000E-2,    0.42700,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   411,    471,'3 ', 4.30000E-3, 5.32000E-2,    0.42700,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   411,    471,'4 ', 4.30000E-3, 5.32000E-2,    0.42700,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   411,    471,'5 ', 4.30000E-3, 5.32000E-2,    0.42700,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   411,    471,'6 ', 4.30000E-3, 5.32000E-2,    0.42700,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   411,    473,'1 ', 4.30000E-3, 5.32000E-2,    0.42700,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   411,    475,'1 ', 4.00000E-3, 4.94000E-2,    0.40000,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   411,    475,'2 ', 4.00000E-3, 4.94000E-2,    0.40000,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   421,    431,'1 ', 4.20000E-3, 5.13000E-2,    0.41200,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,2,   0.00,   1,1.0000
   421,    441,'1 ', 5.40000E-3, 5.00000E-2,    0.18900,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,2,   0.00,   1,1.0000
   431,    472,'1 ', 6.00000E-4, 7.60000E-3,    0.06200,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,2,   0.00,   1,1.0000
   431,    472,'2 ', 6.00000E-4, 7.60000E-3,    0.06200,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,2,   0.00,   1,1.0000
   441,    472,'1 ', 3.90000E-3, 4.75000E-2,    0.38100,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   441,    472,'2 ', 3.90000E-3, 4.75000E-2,    0.38100,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   441,    474,'1 ', 1.80000E-2, 1.22000E-1,    0.79000,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   441,    474,'2 ', 1.80000E-2, 1.22000E-1,    0.79000,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   441,    474,'3 ', 1.80000E-2, 1.22000E-1,    0.79000,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   471,    473,'1 ', 1.20000E-3, 1.52000E-2,    0.12200,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,2,   0.00,   1,1.0000
   471,    473,'2 ', 1.20000E-3, 1.52000E-2,    0.12200,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,2,   0.00,   1,1.0000
   473,    474,'1 ', 1.03000E-2, 7.09000E-2,    0.46000,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,2,   0.00,   1,1.0000
   473,    474,'2 ', 1.03000E-2, 7.09000E-2,    0.46000,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,2,   0.00,   1,1.0000
   481,    482,'1 ', 2.00000E-3, 2.50000E-2,    0.39000,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   481,    482,'2 ', 2.00000E-3, 2.50000E-2,    0.39000,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   482,    483,'1 ', 3.70000E-3, 4.60000E-2,    0.73000,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   482,    483,'2 ', 3.70000E-3, 4.60000E-2,    0.73000,     0.00,     0.00,     0.00, 0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
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   511,    581,'1 ', 2.30000E-2, 1.50000E-1,   0.56000,     0.00,     0.00,     0.00,  0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   511,    581,'2 ', 2.30000E-2, 1.50000E-1,   0.56000,     0.00,     0.00,     0.00,  0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   511,    584,'1 ', 1.30000E-2, 9.50000E-3,   0.43500,     0.00,     0.00,     0.00,  0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   511,    584,'2 ', 1.30000E-2, 9.50000E-3,   0.43500,     0.00,     0.00,     0.00,  0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   521,    581,'1 ', 8.00000E-4, 8.50000E-3,   0.06000,     0.00,     0.00,     0.00,  0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   521,    583,'1 ', 2.50000E-3, 2.80000E-2,   0.17000,     0.00,     0.00,     0.00,  0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   531,    581,'1 ', 8.00000E-4, 8.50000E-3,   0.06000,     0.00,     0.00,     0.00,  0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   531,    583,'1 ', 3.00000E-3, 2.80000E-2,   0.14000,     0.00,     0.00,     0.00,  0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   581,    582,'1 ', 3.00000E-2, 2.20000E-1,   0.90000,     0.00,     0.00,     0.00,  0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   581,    582,'2 ', 3.00000E-2, 2.20000E-1,   0.90000,     0.00,     0.00,     0.00,  0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   581,    583,'1 ', 2.00000E-3, 1.90000E-2,   0.09000,     0.00,     0.00,     0.00,  0.00000,
0.00000,  0.00000,  0.00000,1,1,   0.00,   1,1.0000
   583,    584,'1 ', 1.30000E-2, 9.50000E-3,   0.43500,     0.00,     0.00,     0.00,  0.00000,
0.00000,  0.00000,  0.00000,1,2,   0.00,   1,1.0000
   583,    584,'2 ', 1.30000E-2, 9.50000E-3,   0.43500,     0.00,     0.00,     0.00,  0.00000,
0.00000,  0.00000,  0.00000,1,2,   0.00,   1,1.0000
0 / END OF BRANCH DATA, BEGIN TRANSFORMER DATA
   221,   252,     0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'2_HUNTER    ',1,   1,1.0000
 0.00000E+0, 6.80000E-3,   100.00
0.99435,   0.000,   0.000,     0.00,     0.00,     0.00, 1,    252, 1.10000, 0.90000, 1.05000,
1.00000,  33, 0, 0.00000, 0.00000,  0.000
1.00000,   0.000
   251,   285,     0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'2_K         ',1,   1,1.0000
 0.00000E+0, 6.80000E-3,   100.00
1.00000,   0.000,   0.000,     0.00,     0.00,     0.00, 1,    285, 1.10000, 0.90000, 1.05000,
1.00000,  33, 0, 0.00000, 0.00000,  0.000
1.00000,   0.000
   266,   276,     0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'2_DARLPT    ',1,   1,1.0000
 0.00000E+0, 2.50000E-2,   100.00
1.04375,   0.000,   0.000,     0.00,     0.00,     0.00, 1,    276, 1.10000, 0.90000, 1.05000,
1.00000,  33, 0, 0.00000, 0.00000,  0.000
1.00000,   0.000
   274,   275,     0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'2_PECSHIFT  ',1,   1,1.0000
 0.00000E+0, 6.00000E-4,   100.00
1.10000,   0.000, -30.000,     0.00,     0.00,     0.00, 1,    275, 1.10000, 0.90000, 1.05000,
1.00000,  33, 0, 0.00000, 0.00000,  0.000
1.00000,   0.000
   275,   365,     0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'2_BURONGA   ',1,   1,1.0000
 2.50000E-3, 4.99400E-2,   100.00
1.10000,   0.000, -30.000,     0.00,     0.00,     0.00, 1,    365, 1.10000, 0.90000, 1.05000,
1.00000,  21, 0, 0.00000, 0.00000,  0.000
1.00000,   0.000
```

```
   331,   364,     0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'3_DEDERG    ',1,   1,1.0000
 0.00000E+0, 1.00000E-2,   100.00
1.01250,   0.000,   0.000,     0.00,     0.00,     0.00, 1,    364, 1.10000, 0.90000, 1.05000,
1.00000,  33, 0, 0.00000, 0.00000,  0.000
1.00000,   0.000
   352,   333,     0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'3_SMTS1     ',1,   1,1.0000
 0.00000E+0, 1.20000E-2,   100.00
0.98750,   0.000,   0.000,     0.00,     0.00,     0.00, 1,    333, 1.10000, 0.90000, 1.05000,
1.00000,  33, 0, 0.00000, 0.00000,  0.000
1.00000,   0.000
   351,   361,     0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'3_MOORBL    ',1,   1,1.0000
 0.00000E+0, 9.00000E-3,   100.00
1.00000,   0.000,   0.000,     0.00,     0.00,     0.00, 1,    361, 1.10000, 0.90000, 1.05000,
1.00000,  33, 0, 0.00000, 0.00000,  0.000
1.00000,   0.000
   352,   372,     0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'3_SMTS2     ',1,   1,1.0000
 0.00000E+0, 1.20000E-2,   100.00
0.96875,   0.000,   0.000,     0.00,     0.00,     0.00, 1,    372, 1.10000, 0.90000, 1.05000,
1.00000,  33, 0, 0.00000, 0.00000,  0.000
1.00000,   0.000
   354,   381,     0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'3_HWTS      ',1,   1,1.0000
 0.00000E+0, 1.35000E-2,   100.00
1.00625,   0.000,   0.000,     0.00,     0.00,     0.00, 1,    381, 1.10000, 0.90000, 1.05000,
1.00000,  33, 0, 0.00000, 0.00000,  0.000
1.00000,   0.000
   355,   371,     0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'3_ROTS      ',1,   1,1.0000
 0.00000E+0, 1.60000E-2,   100.00
0.90000,   0.000,   0.000,     0.00,     0.00,     0.00, 1,    371, 1.10000, 0.90000, 1.05000,
1.00000,  33, 0, 0.00000, 0.00000,  0.000
1.00000,   0.000
   475,   481,     0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'4_BR        ',1,   1,1.0000
 0.00000E+0, 2.66667E-3,   100.00
1.00000,   0.000,   0.000,     0.00,     0.00,     0.00, 1,    481, 1.10000, 0.90000, 1.05000,
1.00000,  33, 0, 0.00000, 0.00000,  0.000
1.00000,   0.000
   574,   584,     0,'1 ',1,1,1, 0.00000E+0, 0.00000E+0,2,'5_BUNDEY    ',1,   1,1.0000
 1.28000E-3, 2.54700E-4,   100.00
1.00000,   0.000,   0.000,     0.00,     0.00,     0.00, 1,    574, 1.12500, 0.92500, 1.06250,
1.03750,  17, 0, 0.00000, 0.00000,  0.000
1.00000,   0.000
0 / END OF TRANSFORMER DATA, BEGIN AREA DATA
0 / END OF AREA DATA, BEGIN TWO-TERMINAL DC DATA
0 / END OF TWO-TERMINAL DC DATA, BEGIN VSC DC LINE DATA
0 / END OF VSC DC LINE DATA, BEGIN IMPEDANCE CORRECTION DATA
0 / END OF IMPEDANCE CORRECTION DATA, BEGIN MULTI-TERMINAL DC DATA
0 / END OF MULTI-TERMINAL DC DATA, BEGIN MULTI-SECTION LINE DATA
0 / END OF MULTI-SECTION LINE DATA, BEGIN ZONE DATA
0 / END OF ZONE DATA, BEGIN INTER-AREA TRANSFER DATA
0 / END OF INTER-AREA TRANSFER DATA, BEGIN OWNER DATA
0 / END OF OWNER DATA, BEGIN FACTS DEVICE DATA
0 / END OF FACTS DEVICE DATA, BEGIN SWITCHED SHUNT DATA
0 / END OF SWITCHED SHUNT DATA, BEGIN GNE DATA
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```
0 / END OF GNE DATA
Q
```

A.2 Case 3 dynamic data (DYRE) listing

```
201,'GENSAL', M,8.5,0.05,0.2,1.5,0.0,1.1,0.65,0.25,0.25,0.14,0.0,0.0/HPS
201,'ESAC4A', M,0.0,1.0,-1.0,2.5,13.25,200.0,0.1,10.0,0.0,0.0/HPS
201,'IEEEST', M,1,0,0.00667,0.0,0.00667,0.0,0.3725,0.03845,0.0,0.0,0.0,0.0,
   7.5,7.5,15.38,999,-999,0.0,0.0/HPS
201,'GAST'  , M,0.05,0.4,0.1,1.0,1.2,0.1,2.0,0.05,0.0/HPS

201 'USRMDL' 'B' 'GENINV' 1 1 2 44 16 28 2 0
   0.1 0.1 0.1 0.02 1.0 10.0 1.4 3.0 5.0 50.0 5.0 50.0
   1.0 10.0 0.0 0.5 0.02 1.5 1.2 0.2 0.7 3.0 1.2 0.2
   0.0 0.02 0.0 0.04
   46.50  1.00 47.35  1.00 49.00  1.00 49.85  0.00
   50.15  0.00 51.00 -1.00 52.65 -1.00 53.50 -1.00 /

201 'USRMDL' 'I' 'GENINV' 1 1 2 44 16 28 2 0
   0.1 0.1 0.1 0.02 1.0 10.0 1.4 3.0 5.0 50.0 5.0 50.0
   1.0 10.0 0.0 0.5 0.02 1.5 1.2 0.2 0.7 3.0 1.2 0.2
   0.0 0.02 0.0 0.04
   46.50  1.00 47.35  1.00 49.00  0.34 49.85  0.00
   50.15  0.00 51.00 -0.34 52.65 -1.00 53.50 -1.00 /

211,'GENROU',M,8.5,0.04,0.3,0.08,1.5,0.0,1.8,1.75,0.3,0.7,0.21,0.2,0.0,0.0/BPS
211,'ESAC4A',M,0.0,1.0,-1.0,0.5,1.12,400.0,0.02,10.0,0.0,0.0/BPS
211,'IEEEST',M,1,0,0.00667,0.0,0.00667,0.0,0.128,0.0064,0.0,0.0,0.0,0.0,
   7.5,7.5,5.56,999,-999,0.0,0.0/BPS
211,'GAST'  ,M,0.05,0.4,0.1,1.0,1.2,0.1,2.0,0.2,0.0/BPS

211 'USRMDL' 'B' 'GENINV' 1 1 2 44 16 28 2 0
   0.1 0.1 0.1 0.02 1.0 10.0 1.4 3.0 5.0 50.0 5.0 50.0
   1.0 10.0 0.0 0.5 0.02 1.5 1.2 0.2 0.7 3.0 1.2 0.2
   0.0 0.02 0.0 0.04
   46.50  1.00 47.35  1.00 49.00  1.00 49.85  0.00
   50.15  0.00 51.00 -1.00 52.65 -1.00 53.50 -1.00 /

211 'USRMDL' 'I' 'GENINV' 1 1 2 44 16 28 2 0
   0.1 0.1 0.1 0.02 1.0 10.0 1.4 3.0 5.0 50.0 5.0 50.0
   1.0 10.0 0.0 0.5 0.02 1.5 1.2 0.2 0.7 3.0 1.2 0.2
   0.0 0.02 0.0 0.04
   46.50  1.00 47.35  1.00 49.00  0.34 49.85  0.00
   50.15  0.00 51.00 -0.34 52.65 -1.00 53.50 -1.00 /

221 'USRMDL' 'B' 'VSMINV' 1 1 7 46 11 38
   221 221 0 0 0 1 1
   3.5 0.0 0.0 0.2 0.5 1.2 1.2 0.2 1.5 1.2
   -1.0 1.0 -1.0 1.0 0.1 0.1 0.1 0.1 0.1 1.0
   0.0 4.0 0.0 1.0 0.1 2.0 0.0 0.1 10.0 0.5 0.1 2.0
   0.7 2.0 0.8 10.0 1.2 2.0 1.3 0.02 45.0 0.02 55.0 0.02 1.5 30.0 /
```

```
221 'USRMDL' 'I' 'GENINV' 1 1 2 44 16 28 2 0
   0.1 0.1 0.1 0.02 1.0 10.0 1.4 3.0 5.0 50.0 5.0 50.0
   1.0 10.0 0.0 0.5 0.02 1.5 1.2 0.2 0.7 3.0 1.2 0.2
   0.0 0.02 0.0 0.04
   46.50  1.00 47.35  1.00 49.00  0.34 49.85  0.00
   50.15  0.00 51.00 -0.34 52.65 -1.00 53.50 -1.00 /

231,'GENROU',M,5.0,0.03,2.0,0.25,1.5,0.0,2.3,1.7,0.3,0.4,0.25,0.2,0.0,0.0/VPS
231,'ESAC4A',M,0.0,1.0,-1.0,0.35,0.7,300.0,0.01,10.0,0.0,0.0/VPS
231,'IEEEST',M,1,0,0.0,0.0,0.0,0.0,0.0,0.0,0.0708,0.00667,0.0292,0.00667,
   7.5,7.5,5.72,999,-999,0.0,0.0/VPS
231,'GAST'  ,M,0.05,0.4,0.1,1.0,1.2,0.1,2.0,0.2,0.0/VPS

241,'GENROU',M,8.5,0.04,0.3,0.08,1.25,0.0,1.8,1.75,0.3,0.7,0.21,0.2,0.0,0.0/MPS
241,'ESAC4A',M,0.0,1.0,-1.0,0.5,1.12,400.0,0.02,10.0,0.0,0.0/MPS
241,'IEEEST',M,1,0,0.00667,0.0,0.00667,0.0,0.1,0.0051,0.01,0.00667,0.0,0.0,
   7.5,7.5,6.66,999,-999,0.0,0.0/MPS
241,'GAST'  ,M,0.05,0.4,0.1,1.0,1.2,0.1,2.0,0.2,0.0/MPS

241 'USRMDL' 'B' 'GENINV' 1 1 2 44 16 28 2 0
   0.1 0.1 0.1 0.02 1.0 10.0 1.4 3.0 5.0 50.0 5.0 50.0
   1.0 10.0 0.0 0.5 0.02 1.5 1.2 0.2 0.7 3.0 1.2 0.2
   0.0 0.02 0.0 0.04
   46.50  1.00 47.35  1.00 49.00  1.00 49.85  0.00
   50.15  0.00 51.00 -1.00 52.65 -1.00 53.50 -1.00 /

241 'USRMDL' 'I' 'GENINV' 1 1 2 44 16 28 2 0
   0.1 0.1 0.1 0.02 1.0 10.0 1.4 3.0 5.0 50.0 5.0 50.0
   1.0 10.0 0.0 0.5 0.02 1.5 1.2 0.2 0.7 3.0 1.2 0.2
   0.0 0.02 0.0 0.04
   46.50  1.00 47.35  1.00 49.00  0.34 49.85  0.00
   50.15  0.00 51.00 -0.34 52.65 -1.00 53.50 -1.00 /

266 'USRMDL' 'B' 'GENINV' 1 1 2 44 16 28 2 0
   0.1 0.1 0.1 0.02 1.0 10.0 1.4 3.0 5.0 50.0 5.0 50.0
   1.0 10.0 0.0 0.5 0.02 1.5 1.2 0.2 0.7 3.0 1.2 0.2
   0.0 0.02 0.0 0.04
   46.50  1.00 47.35  1.00 49.00  1.00 49.85  0.00
   50.15  0.00 51.00 -1.00 52.65 -1.00 53.50 -1.00 /

266 'USRMDL' 'I' 'GENINV' 1 1 2 44 16 28 2 0
   0.1 0.1 0.1 0.02 1.0 10.0 1.4 3.0 5.0 50.0 5.0 50.0
   1.0 10.0 0.0 0.5 0.02 1.5 1.2 0.2 0.7 3.0 1.2 0.2
   0.0 0.02 0.0 0.04
   46.50  1.00 47.35  1.00 49.00  0.34 49.85  0.00
   50.15  0.00 51.00 -0.34 52.65 -1.00 53.50 -1.00 /

281 'USRMDL' 'B' 'GENINV' 1 1 2 44 16 28 2 0
   0.1 0.1 0.1 0.02 1.0 10.0 1.4 3.0 5.0 50.0 5.0 50.0
   1.0 10.0 0.0 0.5 0.02 1.5 1.2 0.2 0.7 3.0 1.2 0.2
   0.0 0.02 0.0 0.04
   46.50  1.00 47.35  1.00 49.00  1.00 49.85  0.00
```

```
   50.15  0.00 51.00 -1.00 52.65 -1.00 53.50 -1.00 /

281 'USRMDL' 'I' 'GENINV' 1 1 2 44 16 28 2 0
   0.1 0.1 0.1 0.02 1.0 10.0 1.4 3.0 5.0 50.0 5.0 50.0
   1.0 10.0 0.0 0.5 0.02 1.5 1.2 0.2 0.7 3.0 1.2 0.2
   0.0 0.02 0.0 0.04
   46.50  1.00 47.35  1.00 49.00  0.34 49.85  0.00
   50.15  0.00 51.00 -0.34 52.65 -1.00 53.50 -1.00 /

282 'USRMDL' 'B' 'GENINV' 1 1 2 44 16 28 2 0
   0.1 0.1 0.1 0.02 1.0 10.0 1.4 3.0 5.0 50.0 5.0 50.0
   1.0 10.0 0.0 0.5 0.02 1.5 1.2 0.2 0.7 3.0 1.2 0.2
   0.0 0.02 0.0 0.04
   46.50  1.00 47.35  1.00 49.00  1.00 49.85  0.00
   50.15  0.00 51.00 -1.00 52.65 -1.00 53.50 -1.00 /

282 'USRMDL' 'I' 'GENINV' 1 1 2 44 16 28 2 0
   0.1 0.1 0.1 0.02 1.0 10.0 1.4 3.0 5.0 50.0 5.0 50.0
   1.0 10.0 0.0 0.5 0.02 1.5 1.2 0.2 0.7 3.0 1.2 0.2
   0.0 0.02 0.0 0.04
   46.50  1.00 47.35  1.00 49.00  0.34 49.85  0.00
   50.15  0.00 51.00 -0.34 52.65 -1.00 53.50 -1.00 /

283 'USRMDL' 'I' 'GENINV' 1 1 2 44 16 28 2 0
   0.1 0.1 0.1 0.02 1.0 10.0 1.4 3.0 5.0 50.0 5.0 50.0
   1.0 10.0 0.0 0.5 0.02 1.5 1.2 0.2 0.7 3.0 1.2 0.2
   0.0 0.02 0.0 0.04
   46.50  1.00 47.35  1.00 49.00  0.34 49.85  0.00
   50.15  0.00 51.00 -0.34 52.65 -1.00 53.50 -1.00 /

311 'USRMDL' 'B' 'GENINV' 1 1 2 44 16 28 2 0
   0.1 0.1 0.1 0.02 1.0 10.0 1.4 3.0 5.0 50.0 5.0 50.0
   1.0 10.0 0.0 0.5 0.02 1.5 1.2 0.2 0.7 3.0 1.2 0.2
   0.0 0.02 0.0 0.04
   46.50  1.00 47.35  1.00 49.00  1.00 49.85  0.00
   50.15  0.00 51.00 -1.00 52.65 -1.00 53.50 -1.00 /

311 'USRMDL' 'I' 'GENINV' 1 1 2 44 16 28 2 0
   0.1 0.1 0.1 0.02 1.0 10.0 1.4 3.0 5.0 50.0 5.0 50.0
   1.0 10.0 0.0 0.5 0.02 1.5 1.2 0.2 0.7 3.0 1.2 0.2
   0.0 0.02 0.0 0.04
   46.50  1.00 47.35  1.00 49.00  0.34 49.85  0.00
   50.15  0.00 51.00 -0.34 52.65 -1.00 53.50 -1.00 /

321 'USRMDL' 'B' 'VSMINV' 1 1 7 46 11 38
   321 321 0 0 0 1 1
   3.5 0.0 0.0 0.2 0.5 1.2 1.2 0.2 1.5 1.2
   -1.0 1.0 -1.0 1.0 0.1 0.1 0.1 0.1 0.1 1.0
   0.0 4.0 0.0 1.0 0.1 2.0 0.0 0.1 10.0 0.5 0.1 2.0
   0.7 2.0 0.8 10.0 1.2 2.0 1.3 0.02 45.0 0.02 55.0 0.02 1.5 30.0 /

321 'USRMDL' 'I' 'GENINV' 1 1 2 44 16 28 2 0
```

```
   0.1 0.1 0.1 0.02 1.0 10.0 1.4 3.0 5.0 50.0 5.0 50.0
   1.0 10.0 0.0 0.5 0.02 1.5 1.2 0.2 0.7 3.0 1.2 0.2
   0.0 0.02 0.0 0.04
   46.50  1.00 47.35  1.00 49.00  1.00 49.85  0.00
   50.15  0.00 51.00 -1.00 52.65 -1.00 53.50 -1.00 /

351 'USRMDL' 'B' 'GENINV' 1 1 2 44 16 28 2 0
   0.1 0.1 0.1 0.02 1.0 10.0 1.4 3.0 5.0 50.0 5.0 50.0
   1.0 10.0 0.0 0.5 0.02 1.5 1.2 0.2 0.7 3.0 1.2 0.2
   0.0 0.02 0.0 0.04
   46.50  1.00 47.35  1.00 49.00  1.00 49.85  0.00
   50.15  0.00 51.00 -1.00 52.65 -1.00 53.50 -1.00 /

351 'USRMDL' 'I' 'GENINV' 1 1 2 44 16 28 2 0
   0.1 0.1 0.1 0.02 1.0 10.0 1.4 3.0 5.0 50.0 5.0 50.0
   1.0 10.0 0.0 0.5 0.02 1.5 1.2 0.2 0.7 3.0 1.2 0.2
   0.0 0.02 0.0 0.04
   46.50  1.00 47.35  1.00 49.00  0.34 49.85  0.00
   50.15  0.00 51.00 -0.34 52.65 -1.00 53.50 -1.00 /

351 'USRMDL' 'J' 'GENINV' 1 1 2 44 16 28 2 0
   0.1 0.1 0.1 0.02 1.0 10.0 1.4 3.0 5.0 50.0 5.0 50.0
   1.0 10.0 0.0 0.5 0.02 1.5 1.2 0.2 0.7 3.0 1.2 0.2
   0.0 0.02 0.0 0.04
   46.50  1.00 47.35  1.00 49.00  0.34 49.85  0.00
   50.15  0.00 51.00 -0.34 52.65 -1.00 53.50 -1.00 /

362 'USRMDL' 'B' 'GENINV' 1 1 2 44 16 28 2 0
   0.1 0.1 0.1 0.02 1.0 10.0 1.4 3.0 5.0 50.0 5.0 50.0
   1.0 10.0 0.0 0.5 0.02 1.5 1.2 0.2 0.7 3.0 1.2 0.2
   0.0 0.02 0.0 0.04
   46.50  1.00 47.35  1.00 49.00  1.00 49.85  0.00
   50.15  0.00 51.00 -1.00 52.65 -1.00 53.50 -1.00 /

362 'USRMDL' 'I' 'GENINV' 1 1 2 44 16 28 2 0
   0.1 0.1 0.1 0.02 1.0 10.0 1.4 3.0 5.0 50.0 5.0 50.0
   1.0 10.0 0.0 0.5 0.02 1.5 1.2 0.2 0.7 3.0 1.2 0.2
   0.0 0.02 0.0 0.04
   46.50  1.00 47.35  1.00 49.00  0.34 49.85  0.00
   50.15  0.00 51.00 -0.34 52.65 -1.00 53.50 -1.00 /

363 'USRMDL' 'B' 'GENINV' 1 1 2 44 16 28 2 0
   0.1 0.1 0.1 0.02 1.0 10.0 1.4 3.0 5.0 50.0 5.0 50.0
   1.0 10.0 0.0 0.5 0.02 1.5 1.2 0.2 0.7 3.0 1.2 0.2
   0.0 0.02 0.0 0.04
   46.50  1.00 47.35  1.00 49.00  1.00 49.85  0.00
   50.15  0.00 51.00 -1.00 52.65 -1.00 53.50 -1.00 /

363 'USRMDL' 'I' 'GENINV' 1 1 2 44 16 28 2 0
   0.1 0.1 0.1 0.02 1.0 10.0 1.4 3.0 5.0 50.0 5.0 50.0
   1.0 10.0 0.0 0.5 0.02 1.5 1.2 0.2 0.7 3.0 1.2 0.2
   0.0 0.02 0.0 0.04
```

```
   46.50  1.00 47.35  1.00 49.00  0.34 49.85  0.00
   50.15  0.00 51.00 -0.34 52.65 -1.00 53.50 -1.00 /

365 'USRMDL' 'B' 'GENINV' 1 1 2 44 16 28 2 0
   0.1 0.1 0.1 0.02 1.0 10.0 1.4 3.0 5.0 50.0 5.0 50.0
   1.0 10.0 0.0 0.5 0.02 1.5 1.2 0.2 0.7 3.0 1.2 0.2
   0.0 0.02 0.0 0.04
   46.50  1.00 47.35  1.00 49.00  1.00 49.85  0.00
   50.15  0.00 51.00 -1.00 52.65 -1.00 53.50 -1.00 /

365 'USRMDL' 'I' 'GENINV' 1 1 2 44 16 28 2 0
   0.1 0.1 0.1 0.02 1.0 10.0 1.4 3.0 5.0 50.0 5.0 50.0
   1.0 10.0 0.0 0.5 0.02 1.5 1.2 0.2 0.7 3.0 1.2 0.2
   0.0 0.02 0.0 0.04
   46.50  1.00 47.35  1.00 49.00  0.34 49.85  0.00
   50.15  0.00 51.00 -0.34 52.65 -1.00 53.50 -1.00 /

366 'USRMDL' 'B' 'GENINV' 1 1 2 44 16 28 2 0
   0.1 0.1 0.1 0.02 1.0 10.0 1.4 3.0 5.0 50.0 5.0 50.0
   1.0 10.0 0.0 0.5 0.02 1.5 1.2 0.2 0.7 3.0 1.2 0.2
   0.0 0.02 0.0 0.04
   46.50  1.00 47.35  1.00 49.00  1.00 49.85  0.00
   50.15  0.00 51.00 -1.00 52.65 -1.00 53.50 -1.00 /

366 'USRMDL' 'I' 'GENINV' 1 1 2 44 16 28 2 0
   0.1 0.1 0.1 0.02 1.0 10.0 1.4 3.0 5.0 50.0 5.0 50.0
   1.0 10.0 0.0 0.5 0.02 1.5 1.2 0.2 0.7 3.0 1.2 0.2
   0.0 0.02 0.0 0.04
   46.50  1.00 47.35  1.00 49.00  0.34 49.85  0.00
   50.15  0.00 51.00 -0.34 52.65 -1.00 53.50 -1.00 /

371 'USRMDL' 'B' 'GENINV' 1 1 2 44 16 28 2 0
   0.1 0.1 0.1 0.02 1.0 10.0 1.4 3.0 5.0 50.0 5.0 50.0
   1.0 10.0 0.0 0.5 0.02 1.5 1.2 0.2 0.7 3.0 1.2 0.2
   0.0 0.02 0.0 0.04
   46.50  1.00 47.35  1.00 49.00  1.00 49.85  0.00
   50.15  0.00 51.00 -1.00 52.65 -1.00 53.50 -1.00 /

371 'USRMDL' 'I' 'GENINV' 1 1 2 44 16 28 2 0
   0.1 0.1 0.1 0.02 1.0 10.0 1.4 3.0 5.0 50.0 5.0 50.0
   1.0 10.0 0.0 0.5 0.02 1.5 1.2 0.2 0.7 3.0 1.2 0.2
   0.0 0.02 0.0 0.04
   46.50  1.00 47.35  1.00 49.00  0.34 49.85  0.00
   50.15  0.00 51.00 -0.34 52.65 -1.00 53.50 -1.00 /

411,'GENROU',M,5.0,0.03,2.0,0.25,2.0,0.0,2.3,1.7,0.3,0.4,0.25,0.2,0.0,0.0/TPS
411,'ESAC4A',M,0.0,1.0,-1.0,4.0,40.0,300.0,0.1,10.0,0.0,0.0/TPS
411,'IEEEST',M,1,0,0.0,0.0,0.0,0.0,0.0,0.0,0.2083,0.00667,0.2083,0.00667,
   7.5,7.5,7.15,999,-999,0.0,0.0/TPS
411,'GAST'  ,M,0.05,0.4,0.1,1.0,1.2,0.1,2.0,0.2,0.0/TPS

411 'USRMDL' 'B' 'GENINV' 1 1 2 44 16 28 2 0
```

```
   0.1 0.1 0.1 0.02 1.0 10.0 1.4 3.0 5.0 50.0 5.0 50.0
   1.0 10.0 0.0 0.5 0.02 1.5 1.2 0.2 0.7 3.0 1.2 0.2
   0.0 0.02 0.0 0.04
   46.50  1.00 47.35  1.00 49.00  1.00 49.85  0.00
   50.15  0.00 51.00 -1.00 52.65 -1.00 53.50 -1.00 /

421 'USRMDL' 'B' 'GENINV' 1 1 2 44 16 28 2 0
   0.1 0.1 0.1 0.02 1.0 10.0 1.4 3.0 5.0 50.0 5.0 50.0
   1.0 10.0 0.0 0.5 0.02 1.5 1.2 0.2 0.7 3.0 1.2 0.2
   0.0 0.02 0.0 0.04
   46.50  1.00 47.35  1.00 49.00  1.00 49.85  0.00
   50.15  0.00 51.00 -1.00 52.65 -1.00 53.50 -1.00 /

421 'USRMDL' 'I' 'GENINV' 1 1 2 44 16 28 2 0
   0.1 0.1 0.1 0.02 1.0 10.0 1.4 3.0 5.0 50.0 5.0 50.0
   1.0 10.0 0.0 0.5 0.02 1.5 1.2 0.2 0.7 3.0 1.2 0.2
   0.0 0.02 0.0 0.04
   46.50  1.00 47.35  1.00 49.00  0.34 49.85  0.00
   50.15  0.00 51.00 -0.34 52.65 -1.00 53.50 -1.00 /

431,'GENROU',M,5.0,0.03,2.0,0.25,2.0,0.0,2.3,1.7,0.3,0.4,0.25,0.2,0.0,0.0/SPS
431,'ESAC4A',M,0.0,1.0,-1.0,0.35,0.7,300.0,0.01,10.0,0.0,0.0/SPS
431,'IEEEST',M,1,0,0.00667,0.0,0.00667,0.0,0.0909,0.002067,0.0,0.0,0.0,0.0,
   7.5,7.5,6.32,999,-999,0.0,0.0/SPS
431,'GAST'  ,M,0.05,0.4,0.1,1.0,1.2,0.1,2.0,0.2,0.0/SPS

431 'USRMDL' 'B' 'GENINV' 1 1 2 44 16 28 2 0
   0.1 0.1 0.1 0.02 1.0 10.0 1.4 3.0 5.0 50.0 5.0 50.0
   1.0 10.0 0.0 0.5 0.02 1.5 1.2 0.2 0.7 3.0 1.2 0.2
   0.0 0.02 0.0 0.04
   46.50  1.00 47.35  1.00 49.00  1.00 49.85  0.00
   50.15  0.00 51.00 -1.00 52.65 -1.00 53.50 -1.00 /

431 'USRMDL' 'I' 'VSMINV' 1 1 7 46 11 38
   431 431 0 0 0 1 1
   3.5 0.0 0.0 0.2 0.5 1.2 1.2 0.2 1.5 1.2
   -1.0 1.0 -1.0 1.0 0.1 0.1 0.1 0.1 0.1 1.0
   0.0 4.0 0.0 1.0 0.1 2.0 0.0 0.1 10.0 0.5 0.1 2.0
   0.7 2.0 0.8 10.0 1.2 2.0 1.3 0.02 45.0 0.02 55.0 0.02 1.5 30.0 /

441,'GENROU',M,9.0,0.04,1.4,0.13,2.0,0.0,2.2,1.4,0.32,0.75,0.24,0.18,0.0,0.0/GPS
441,'ESAC4A',M,0.0,1.0,-1.0,0.136,0.0232,250.0,0.2,10.0,0.0,0.0/GPS
441,'IEEEST',M,1,0,0.00667,0.0,0.00667,0.0,0.1154,0.005917,0.0,0.0,0.0,0.0,
   7.5,7.5,6.06,999,-999,0.0,0.0/GPS
441,'GAST'  ,M,0.05,0.4,0.1,1.0,1.2,0.1,2.0,0.2,0.0/GPS

441 'USRMDL' 'B' 'GENINV' 1 1 2 44 16 28 2 0
   0.1 0.1 0.1 0.02 1.0 10.0 1.4 3.0 5.0 50.0 5.0 50.0
   1.0 10.0 0.0 0.5 0.02 1.5 1.2 0.2 0.7 3.0 1.2 0.2
   0.0 0.02 0.0 0.04
   46.50  1.00 47.35  1.00 49.00  1.00 49.85  0.00
   50.15  0.00 51.00 -1.00 52.65 -1.00 53.50 -1.00 /
```

```
471 'USRMDL' 'B' 'GENINV' 1 1 2 44 16 28 2 0
   0.1 0.1 0.1 0.02 1.0 10.0 1.4 3.0 5.0 50.0 5.0 50.0
   1.0 10.0 0.0 0.5 0.02 1.5 1.2 0.2 0.7 3.0 1.2 0.2
   0.0 0.02 0.0 0.04
   46.50  1.00 47.35  1.00 49.00  1.00 49.85  0.00
   50.15  0.00 51.00 -1.00 52.65 -1.00 53.50 -1.00 /

472 'USRMDL' 'B' 'GENINV' 1 1 2 44 16 28 2 0
   0.1 0.1 0.1 0.02 1.0 10.0 1.4 3.0 5.0 50.0 5.0 50.0
   1.0 10.0 0.0 0.5 0.02 1.5 1.2 0.2 0.7 3.0 1.2 0.2
   0.0 0.02 0.0 0.04
   46.50  1.00 47.35  1.00 49.00  1.00 49.85  0.00
   50.15  0.00 51.00 -1.00 52.65 -1.00 53.50 -1.00 /

472 'USRMDL' 'I' 'GENINV' 1 1 2 44 16 28 2 0
   0.1 0.1 0.1 0.02 1.0 10.0 1.4 3.0 5.0 50.0 5.0 50.0
   1.0 10.0 0.0 0.5 0.02 1.5 1.2 0.2 0.7 3.0 1.2 0.2
   0.0 0.02 0.0 0.04
   46.50  1.00 47.35  1.00 49.00  0.34 49.85  0.00
   50.15  0.00 51.00 -0.34 52.65 -1.00 53.50 -1.00 /

474 'USRMDL' 'B' 'GENINV' 1 1 2 44 16 28 2 0
   0.1 0.1 0.1 0.02 1.0 10.0 1.4 3.0 5.0 50.0 5.0 50.0
   1.0 10.0 0.0 0.5 0.02 1.5 1.2 0.2 0.7 3.0 1.2 0.2
   0.0 0.02 0.0 0.04
   46.50  1.00 47.35  1.00 49.00  1.00 49.85  0.00
   50.15  0.00 51.00 -1.00 52.65 -1.00 53.50 -1.00 /

474 'USRMDL' 'I' 'GENINV' 1 1 2 44 16 28 2 0
   0.1 0.1 0.1 0.02 1.0 10.0 1.4 3.0 5.0 50.0 5.0 50.0
   1.0 10.0 0.0 0.5 0.02 1.5 1.2 0.2 0.7 3.0 1.2 0.2
   0.0 0.02 0.0 0.04
   46.50  1.00 47.35  1.00 49.00  0.34 49.85  0.00
   50.15  0.00 51.00 -0.34 52.65 -1.00 53.50 -1.00 /

475 'USRMDL' 'B' 'GENINV' 1 1 2 44 16 28 2 0
   0.1 0.1 0.1 0.02 1.0 10.0 1.4 3.0 5.0 50.0 5.0 50.0
   1.0 10.0 0.0 0.5 0.02 1.5 1.2 0.2 0.7 3.0 1.2 0.2
   0.0 0.02 0.0 0.04
   46.50  1.00 47.35  1.00 49.00  1.00 49.85  0.00
   50.15  0.00 51.00 -1.00 52.65 -1.00 53.50 -1.00 /

475 'USRMDL' 'I' 'GENINV' 1 1 2 44 16 28 2 0
   0.1 0.1 0.1 0.02 1.0 10.0 1.4 3.0 5.0 50.0 5.0 50.0
   1.0 10.0 0.0 0.5 0.02 1.5 1.2 0.2 0.7 3.0 1.2 0.2
   0.0 0.02 0.0 0.04
   46.50  1.00 47.35  1.00 49.00  0.34 49.85  0.00
   50.15  0.00 51.00 -0.34 52.65 -1.00 53.50 -1.00 /

475 'USRMDL' 'J' 'GENINV' 1 1 2 44 16 28 2 0
   0.1 0.1 0.1 0.02 1.0 10.0 1.4 3.0 5.0 50.0 5.0 50.0
```

```
   1.0 10.0 0.0 0.5 0.02 1.5 1.2 0.2 0.7 3.0 1.2 0.2
   0.0 0.02 0.0 0.04
   46.50  1.00 47.35  1.00 49.00  0.34 49.85  0.00
   50.15  0.00 51.00 -0.34 52.65 -1.00 53.50 -1.00 /

511 'USRMDL' 'I' 'GENINV' 1 1 2 44 16 28 2 0
   0.1 0.1 0.1 0.02 1.0 10.0 1.4 3.0 5.0 50.0 5.0 50.0
   1.0 10.0 0.0 0.5 0.02 1.5 1.2 0.2 0.7 3.0 1.2 0.2
   0.0 0.02 0.0 0.04
   46.50  1.00 47.35  1.00 49.00  0.34 49.85  0.00
   50.15  0.00 51.00 -0.34 52.65 -1.00 53.50 -1.00 /

521 'USRMDL' 'B' 'GENINV' 1 1 2 44 16 28 2 0
   0.1 0.1 0.1 0.02 1.0 10.0 1.4 3.0 5.0 50.0 5.0 50.0
   1.0 10.0 0.0 0.5 0.02 1.5 1.2 0.2 0.7 3.0 1.2 0.2
   0.0 0.02 0.0 0.04
   46.50  1.00 47.35  1.00 49.00  1.00 49.85  0.00
   50.15  0.00 51.00 -1.00 52.65 -1.00 53.50 -1.00 /

521 'USRMDL' 'I' 'GENINV' 1 1 2 44 16 28 2 0
   0.1 0.1 0.1 0.02 1.0 10.0 1.4 3.0 5.0 50.0 5.0 50.0
   1.0 10.0 0.0 0.5 0.02 1.5 1.2 0.2 0.7 3.0 1.2 0.2
   0.0 0.02 0.0 0.04
   46.50  1.00 47.35  1.00 49.00  0.34 49.85  0.00
   50.15  0.00 51.00 -0.34 52.65 -1.00 53.50 -1.00 /

531 'USRMDL' 'B' 'GENINV' 1 1 2 44 16 28 2 0
   0.1 0.1 0.1 0.02 1.0 10.0 1.4 3.0 5.0 50.0 5.0 50.0
   1.0 10.0 0.0 0.5 0.02 1.5 1.2 0.2 0.7 3.0 1.2 0.2
   0.0 0.02 0.0 0.04
   46.50  1.00 47.35  1.00 49.00  1.00 49.85  0.00
   50.15  0.00 51.00 -1.00 52.65 -1.00 53.50 -1.00 /

531 'USRMDL' 'I' 'GENINV' 1 1 2 44 16 28 2 0
   0.1 0.1 0.1 0.02 1.0 10.0 1.4 3.0 5.0 50.0 5.0 50.0
   1.0 10.0 0.0 0.5 0.02 1.5 1.2 0.2 0.7 3.0 1.2 0.2
   0.0 0.02 0.0 0.04
   46.50  1.00 47.35  1.00 49.00  0.34 49.85  0.00
   50.15  0.00 51.00 -0.34 52.65 -1.00 53.50 -1.00 /

581 'USRMDL' 'B' 'GENINV' 1 1 2 44 16 28 2 0
   0.1 0.1 0.1 0.02 1.0 10.0 1.4 3.0 5.0 50.0 5.0 50.0
   1.0 10.0 0.0 0.5 0.02 1.5 1.2 0.2 0.7 3.0 1.2 0.2
   0.0 0.02 0.0 0.04
   46.50  1.00 47.35  1.00 49.00  1.00 49.85  0.00
   50.15  0.00 51.00 -1.00 52.65 -1.00 53.50 -1.00 /

582 'USRMDL' 'B' 'GENINV' 1 1 2 44 16 28 2 0
   0.1 0.1 0.1 0.02 1.0 10.0 1.4 3.0 5.0 50.0 5.0 50.0
   1.0 10.0 0.0 0.5 0.02 1.5 1.2 0.2 0.7 3.0 1.2 0.2
   0.0 0.02 0.0 0.04
   46.50  1.00 47.35  1.00 49.00  1.00 49.85  0.00
```

```
   50.15  0.00 51.00 -1.00 52.65 -1.00 53.50 -1.00 /

583 'USRMDL' 'B' 'GENINV' 1 1 2 44 16 28 2 0
   0.1 0.1 0.1 0.02 1.0 10.0 1.4 3.0 5.0 50.0 5.0 50.0
   1.0 10.0 0.0 0.5 0.02 1.5 1.2 0.2 0.7 3.0 1.2 0.2
   0.0 0.02 0.0 0.04
   46.50  1.00 47.35  1.00 49.00  1.00 49.85  0.00
   50.15  0.00 51.00 -1.00 52.65 -1.00 53.50 -1.00 /

584 'USRMDL' 'I' 'GENINV' 1 1 2 44 16 28 2 0
   0.1 0.1 0.1 0.02 1.0 10.0 1.4 3.0 5.0 50.0 5.0 50.0
   1.0 10.0 0.0 0.5 0.02 1.5 1.2 0.2 0.7 3.0 1.2 0.2
   0.0 0.02 0.0 0.04
   46.50  1.00 47.35  1.00 49.00  0.34 49.85  0.00
   50.15  0.00 51.00 -0.34 52.65 -1.00 53.50 -1.00 /

201,'GENROU',Q,7.67,0.042,0.9326,0.05723,2.5,0.0,1.78,1.6,0.209,0.253,0.152,0.151,0.1445,0.575
6/DVSC
201,'ESAC4A',Q,0.0,1.0,-1.0,0.2,0.8,300.0,0.01,10.0,0.0,0.0/

211,'GENROU',Q,7.67,0.042,0.9326,0.05723,2.5,0.0,1.78,1.6,0.209,0.253,0.152,0.151,0.1445,0.575
6/DVSC
211,'ESAC4A',Q,0.0,1.0,-1.0,0.2,0.8,300.0,0.01,10.0,0.0,0.0/

365,'GENROU',Q,7.67,0.042,0.9326,0.05723,2.5,0.0,1.78,1.6,0.209,0.253,0.152,0.151,0.1445,0.575
6/DVSC
365,'ESAC4A',Q,0.0,1.0,-1.0,0.2,0.8,300.0,0.01,10.0,0.0,0.0/

475,'GENROU',Q,7.67,0.042,0.9326,0.05723,2.5,0.0,1.78,1.6,0.209,0.253,0.152,0.151,0.1445,0.575
6/DVSC
475,'ESAC4A',Q,0.0,1.0,-1.0,0.2,0.8,300.0,0.01,10.0,0.0,0.0/

511,'GENROU',Q,7.67,0.042,0.9326,0.05723,2.5,0.0,1.78,1.6,0.209,0.253,0.152,0.151,0.1445,0.575
6/DVSC
511,'ESAC4A',Q,0.0,1.0,-1.0,0.2,0.8,300.0,0.01,10.0,0.0,0.0/

581,'GENROU',Q,10.5,0.041,2.5,0.15,2.5,0.0,1.65,1.56,0.182,0.362,0.135,0.105,0.075,0.305/TBSC
581,'ESAC4A',Q,0.0,1.0,-1.0,0.2,0.8,300.0,0.01,10.0,0.0,0.0/

471 'CSTATT' 'Q' 1.0 1.0 1.0 0.005 1.25 0.01 999 -999 2.67 2.67 0.2 1.2 0.1 0.5/
```