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VALUE OF DEMAND FLEXIBILITY FOR PROVIDING ANCILLARY SERVICES: A STUDY OF THE IRISH DS3 MARKET

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ABSTRACT

This paper evaluates the potential of consumer flexibility to reduce expenditure on the ancillary services required to manage wind variability. Flexibility is provided by turning up or turning down a portfolio of heat pumps in response to system imbalance.

We proposed two new ancillary service products to the Irish DS3 Market, Demand-Turn-Up$^+$ (DTU$^+$) and Demand-Turn-Down$^+$ (DTD$^+$). A model for simulating these two services was developed for three scenarios: Flexibility using thermal storage, Flexibility using battery and finally flexibility by shifting or reducing heating loads without storage. A portfolio of one million heat pumps was simulated, controlling these devices in response to system imbalance for the month of February 2019. A time series of DS3 payments was used to calculate the associated savings in DS3 spend for each settlement period.

The results show that demand flexibility can reduce spending on ancillary services by 42%, while reducing CO_2 emissions by 67% by switching from oil-fired heating to heat pumps. This could help transition one million homes (one-third of the Irish housing stock) to low carbon heating.

KEYWORDS

Demand Flexibility, DS3 Ancillary Services, Business Models, Demand Turn-up, Demand Turn-down, Heat Pumps

INTRODUCTION

A growing concern for climate change has increased uptake in renewables such as wind generation. However, the variability of such renewables has increased the need for ancillary services to ensure security of the grid and power quality. The Irish all-island electrical power system has integrated the highest levels of non-dispatchable renewable energy into an electrically isolated, standalone electrical grid anywhere in the world, with the system achieving 40% renewable electricity ahead of its 2020 target [1].

The DS3 market is the ancillary services market for the island of Ireland and it is set up to handle up to 75% system non-synchronous penetration (SNSP) which is mostly wind, by 2020 [2]. The system can currently accommodate up to 65% SNSP - this is world first.[3]. DS3 is a pioneering ancillary services market, which includes 14 separate products, spanning response times from 300 milliseconds to 16 hours [4]. Most of the wind resource in the Irish power system is connected at low voltage distribution levels. Hence there are opportunities for consumer-owned flexibility to be used to manage the variability locally as opposed to traditional system-operator controlled resource which would typically be more suited to transmission level connected wind resource and are frequently provided by fossil fuel generators.

About 68% of homes in Northern Ireland use oil boilers, 82% of these are in rural areas, not connected to the gas grid, mainly sparsely distributed and hence not suitable for district heating [5]. With the new ban on connecting new homes to gas heating from 2025 [6], it is expected that heat pumps will be a major player in decarbonising heating in rural areas. Currently adoption of low carbon heating such as heat pumps seems to be expensive when compared with other heating forms such as gas or oil heating [7], this has hampered the adoption of these technologies and is the main barrier to heat decarbonisation in Northern Ireland. Hence, for such low carbon technology to be economical, other values streams must be monetised. Thermal devices, particularly when configured with storage, are highly flexible and could be used to provide load response to help manage intermittency in wind generation.

This paper seeks to evaluate the potential of flexibility from a portfolio of domestic heat pumps to provide or displace ancillary services. Demand response is considered a potentially valuable stream of income that flexible consumers can monetise. This can be implemented by either a signal to turn up demand at times of high wind or better still, by shaping a portfolio of heating demand to match the system imbalance profile. This would provide cheap and even free electricity for large numbers of domestic consumers (including vulnerable consumers, at risk of fuel poverty) as well as reducing the cost of system services, which in turn will reduce normal electricity prices for all consumers, a win-win situation.

We propose two new ancillary service products that would allow demand side response to reduce system imbalance, they are named Demand-Turn-Up$^+$ (DTU$^+$) and Demand-Turn-Down$^+$ (DTD$^+$). Demand Turn Up was first introduced by the UK's National Grid to refer to the service of paying large energy users and generators to either increase demand or reduce generation [8]. In this paper we extend the terms, connoting them as DTU$^+$ and DTD$^+$, and describe the new terms as the continuous response of a portfolio of consumer demand, which is used to reduce system imbalances. We then provide a detailed description of the service and recommend its possible implementation in the Irish power system.

DS3 uses scalars to incentivize the provision of ancillary services when the system needs it most; this is called the Temporal Scarcity Scalar. As SNSP increases, the temporal scarcity scalar multiplies DS3 payments. Table 1 shows the list of current ancillary services, their time scales, temporal scarcity scalar and payment rates. The purpose of the proposed new services is to reduce system imbalance to a point where the quantity of other ancillary services (TOR 1 - RM8) needed are small, and possibly some services might no longer be needed.

Table 1. List of current DS3 market services, time limits, lead times, payments rates and scalars as of September 2019

DS3 Product	Time Scale	Payment Rate	Temporal Scarcity Scalar Values			
			0-50% SNSP	50-60% SNSP	60-70% SNSP	70-75% SNSP
Synchronous Inertial Response (SIR)	300ms	£0.0045/ MWs^{2}h	1	1	4.7	6.3
Primary Operating Reserve (POR)	5-15 sec	£2.91/ MWh	1	1	4.7	6.3
Secondary Operating Reserve (SOR)	15-90 sec	£1.76/ MWh	1	1	4.7	6.3
Tertiary Operating Reserve 1 (TOR1)	90-300 sec	£1.39/ MWh	1	1	4.7	6.3
Tertiary Operating Reserve 2 (TOR2)	5-15 min	£1.11/ MWh	1	1	4.7	6.3
Replacement Reserve (Synchronised) (RRS)	15-60 min	£0.22/ MWh	1	1	4.7	6.3
Replacement Reserve (De-Synchronised) (RRD)	15-60 min	£0.50/ MWh	1	1	4.7	6.3
Ramping Margin 1 (RM1)	1-3 hour	£0.11/ MWh	1	1	4.7	6.3
Ramping Margin 3 (RM3)	3-8 hour	£0.16/ MWh	1	1	4.7	6.3
Ramping Margin 8 (RM8)	8-16 hour	£0.14/ MWh	1	1	4.7	6.3
Steady State reactive Power (SSRP)		£0.21/ MVArh	1	1	4.7	6.3
Fast Frequency Response (FFR)	2-10 sec	£1.94/ MWh	0	1	4.7	6.3
Fast Post Fault Active Power Recovery (FPFAPR)		£0.13/ MWh	0	0	0	6.3
Dynamic Reactive Response (DRR)		£0.04/ MWh	0	0	0	6.3

METHODOLOGY

Heat pump load profiles with one-minute resolution were sourced from the datasets of the Consumer Led Network Revolution trial. DS3 Payments for the month of February 2019 were provided by the System Operator (Eirgrid) and used to simulate several scenarios of demand response. 75 distinct load profiles were scaled to one million consumers using a continuous loop in the simulation.

Figure 1 shows the graph of system generation for the month of February. From the graph we see that at times of high wind, SNSP crosses 60% and hence temporal scarcity scalar of 4.7 is applied. During this period as shown in Figure 2, payments for steady state reactive power (SSRP) is highest, getting up to 4k (£4000) for each 30-minute settlement period. POR sometimes gets above 4K, SOR, SIR, TOR1 and TOR2 sit between 2k-3K. RRD, RM8 and RM3 receive between 1-2K, while other products receive less than 1K payments.

Figure 1. System Generation, Demand and Wind Production for February 2019

Figure 2. DS3 payments in 30 min period and applied scarcity scaler for February 2019

Given that the ability of an aggregated portfolio of heat pumps to respond to frequency under 15 seconds lead-time is still in question, only TOR 1 – RM8 were considered in this research. Figure 4 shows the sum of TOR1-RM8 payments in each 30 min settlement period and the system imbalance in each period.

Three scenarios were considered for DTU^+ and DTD^+:

Scenario A- The excess system electricity when imbalance is positive (generation exceeds demand) is used to meet the demand of the heating loads and excess imbalance is used to charge a buffer tank to be released first when imbalance is negative (demand exceeds generation). The thermal store was modelled using a Dimplex 500L buffer tank (PSW500), which cost £921.50 with loss rate of 3.024kW/24hrs [9]. A high temperature heat pump was used to heat the buffer tank up to 85ºC, with 55ºC return temperature from the radiators, the buffer tank can store 16.75kW of heat using Equation 1.

$$Q = \frac{m.c.\Delta T}{3600} \quad (1)$$

Scenario B is similar to A, however in this case a battery is used as the storage technology. SonnenBatterie ECO 8.6 which cost £7904 (vat. Inc.) with 6kW capacity, 2.5kW inverter charging and discharging power, and a round-trip efficiency of 83% was used to model the battery [10].

Scenario C – In addition to using positive imbalance to meet consumer load, heat pumps were turned on at times of low demand and positive system imbalance. The flexibility of turning on the heat pump is limited to the time of day and the pre-event temperature of the house. Beyond a certain limit, further heating of the house could cause discomfort to residents. In order to minimise discomfort due to overheating, each heat pump is allowed to turn-up heating for a limited time, set to 30 minutes for the simulation; and is required to wait thereafter for a hold period (in this case 3hours) before it is eligible to participate in demand turn up again.

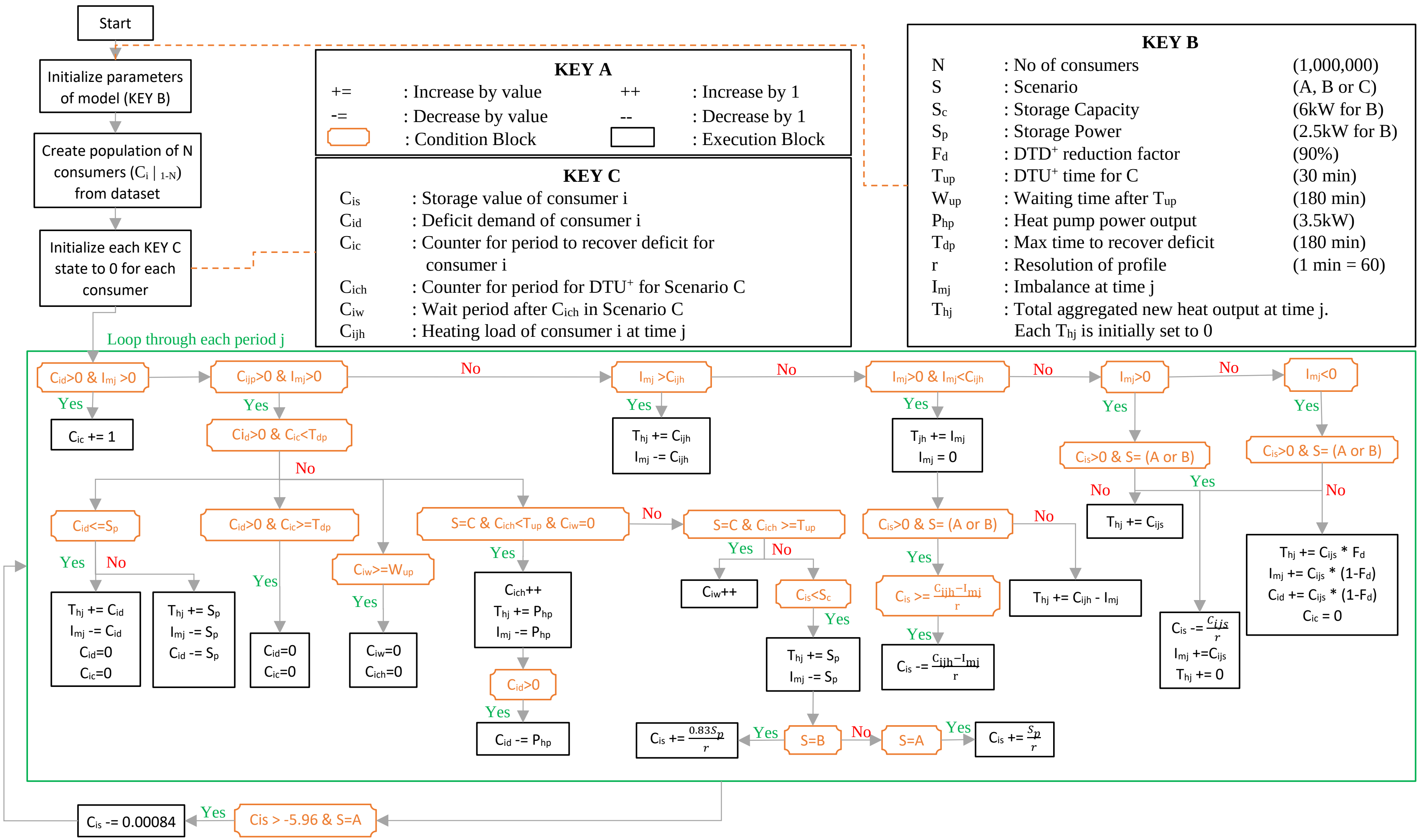

Figure 3. Flowchart of DTU+ and DTD+ Simulation Model

In DTD+ mode (i.e. when demand exceeds generation), the system first turns to thermal storage (Scenario A) or battery (Scenario B), before reducing heat pumps output by 90%, this value could also be used to refer to the efficiency of the demand reduction system. The heat pump is turned on for longer to compensate for the deficit when the system comes back to positive imbalance within a 3hour window, after which remaining deficit demand is taken as unneeded. A flowchart showing the steps taken in the full simulation is shown in Figure 3.

Figure 4. Sum of DS3 Payments (£) in each 30 minutes period and System Imbalance for February 2019

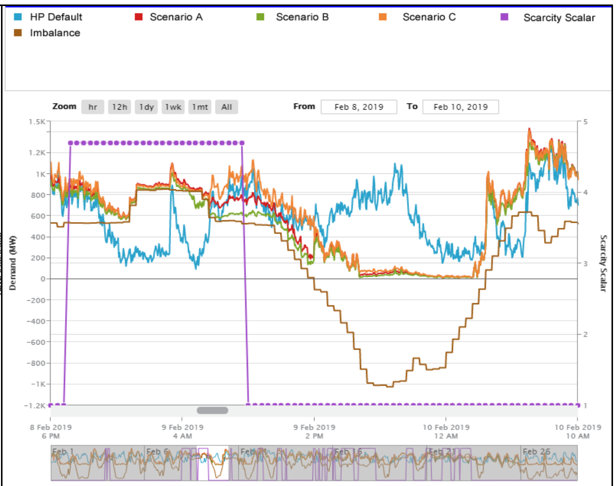

Figure 5. Aggregated Heating load profiles under the three scenarios

RESULTS

Figure 5 shows the aggregated consumers heating load (HP Default), and the new heating load profiles under scenario A, B and C demand response simulations. During high SNSP events (scarcity scalar of 4.7) and positive system imbalance, the heating loads under the three scenario increases, while during negative system imbalance the heating load drops for the three scenarios.

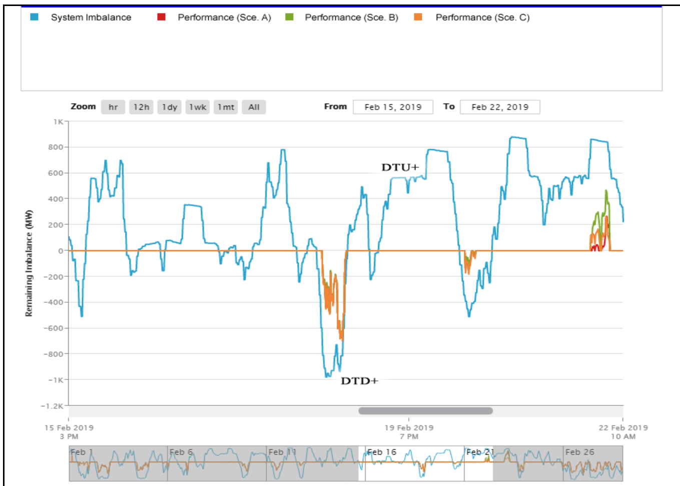

Figure 6. Performance of the three Demand Response scenarios to System Imbalance

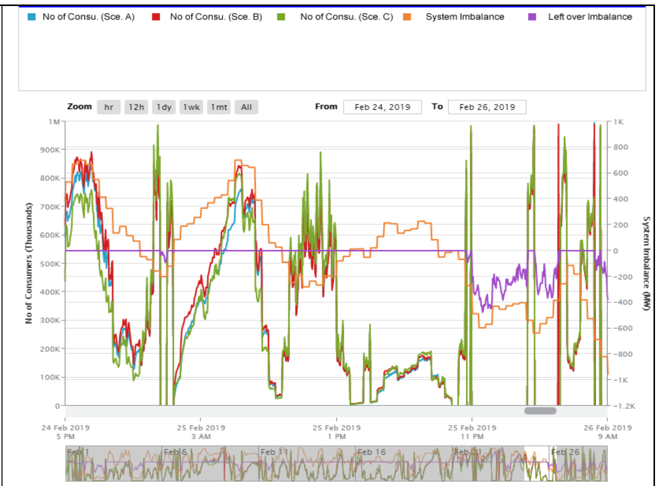

Figure 7. No of consumers activated to respond to system imbalance in the three scenarios

The performance of the three demand response scenarios to system imbalance is shown in Figure 6. From the graph, we see that the aggregated portfolio could provide 100% reduction most of the time, however, there are still imbalances remaining at a few other times, due to a) few heating loads being scheduled when a large negative imbalance event occurred, hence there was not enough capacity to be reduced; or b) when positive imbalance has occurred for quite some time and there is no more capacity for the portfolio to add more demand. This can then be resolved by dispatching other DS3 products at a reduced quantity, or by increasing the number of consumers in the program. An aggregator would need to work out the optimal number of consumers to make a DTU$^+$ or DTD$^+$ bid commercially viable.

The number of consumers that responded to reduce system imbalance at each time step was recorded and is shown in Figure 7. The model in Figure 3 can also be extended to determine the optimal number of consumers for an aggregator to recruit in their program.

The total DS3 spend for February 2019 was £13,057,479, out of which £5,872,023 (44.97%) was for TOR1-RM8 (i.e. TOR1, TOR2, RRS, RRD, RM1, RM3 and RM8) services. Table 2 shows the percentage of total DS3 spend reduced for each of the three scenarios: 42.51%, 42.26%, 42.74% for scenario A, B and C respectively. It is also worth noting that scenarios A and B minimise the risk of discomfort to consumers, as they do not experience any change in the quantity of heat delivered during DTU$^+$ and some period of DTD$^+$ because storage is used.

Table 2. Savings of DS3 Spend under the three Scenarios for February 2019

Total DS3 Pay	TOR1-RM8 Pay		SCENARIO A	SCENARIO B	SCENARIO C
£13,057,479	£5,872,023 (44.97%)	**Savings**	£5,550,902.9	£5,518,294.7	£5,581,272
		% Saved	42.51%	42.26%	42.74%

As stated earlier, two-thirds of Northern-Ireland homes still use oil boilers and a switch to low carbon heating is vital to meet emissions reduction targets. Table 3 shows the reduction in CO_2 emissions from switching oil heating to heat pumps is 58.47%. It also shows that more reductions are achieved under the three scenarios (67.5% for Scenario A) because more demand is shifted to times of high wind and low CO_2 intensity in the grid. Figure 8 shows the graph of CO_2 emissions in the three scenarios.

Table 3. Reduction in CO2 Emissions from the three scenarios when compared to Oil Heating

	Oil Heating	Heat Pumps (Normal)	SCENARIO A	SCENARIO B	SCENARIO C
CO_2 Emissions (tonnes)	17,454,019	7,248,527	5,671,073	5,468,205	6,091,884
% Reduced		58.47%	67.50%	68.67%	65.09%

Figure 8. CO_2 Emissions of Oil heating vs Heat pumps in normal operation vs Heat pumps in the three Scenarios

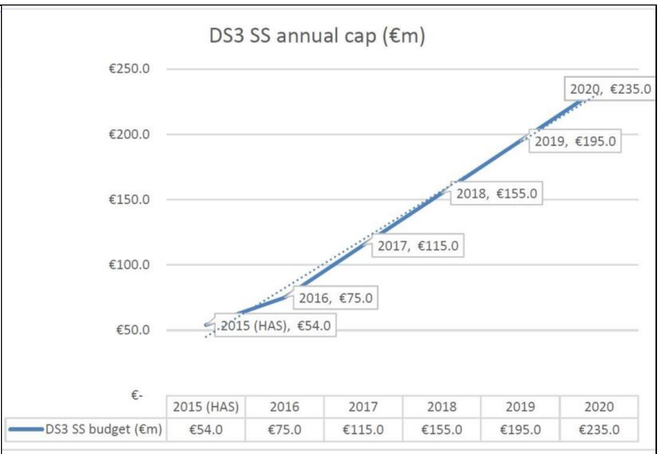

Figure 9. DS3 system services annual payment cap

CONCLUSION

The results show that demand response from one million heat pumps (one-third of the Irish housing stock [11], [12]) can reduce DS3 spend by 42%. Annual DS3 spend is subject to an expenditure cap as shown in Figure 9. However, this is likely to increase greatly in order to meet the new 70% renewable electricity by 2030 [13]. Hence the need to adopt the proposed scheme as soon as possible to reduce the cost of system services.

Further Research

Further research would investigate and propose pricing structures for DTU^+ and DTD^+ services and calculate potential savings for the consumers. The risk of discomfort from increasing or decreasing consumer demand is best represented in terms of temperature changes in homes, hence an advanced model, using consumers' temperature set point and comfort range to quantify the available capacity for providing DTU^+ and DTD^+, as well as the impact on the house temperature, is necessary.

Although this paper suggests new separate services for demand response to provide grid balancing, there is no doubt that demand response could participate directly in existing DS3 market products such as TOR1, TOR2, TOR3, RM1, RM3, RM8. However, the speed at which a heat pump can ramp up and ramp down in response to frequency, coupled with delays in communication, makes its suitability for providing certain services such as FFR, POR and SOR doubtful and hence more research and trails are needed in this area. It has been proven that battery storage can provide SOR, POR, FFR and even SIR (300 milliseconds) through synthetic inertial response [14].

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