Effect of Governor Deadbands on Valve Travel using Long-Term Dynamic Simulation

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Abstract—This paper investigates the impact of governor deadbands on valve travel using a novel long-term dynamic (LTD) simulation software environment. The Python based LTD software utilizes a commercial power-flow solver to execute a sequence of power flows that is shown to capture long-term power system dynamics with acceptable accuracy. While classic transient stability simulation is sufficient for investigating the impact of governor deadbands on primary frequency response, LTD software is needed for analyzing the impact of governor deadbands on fuel valve travel over longer periods of time. The LTD software enables simulations from tens of minutes to hours on full system base cases. Cumulative valve travel is proposed as a metric for evaluating the impact of various deadband settings. It is shown that use of specific governor deadband settings can actually increase cumulative valve travel over what would be expected without a deadband.

Index Terms—Governor deadband, long-term dynamic simulation, time-sequenced power flow, valve travel

I. INTRODUCTION

Governor deadbands are commonly implemented in turbine speed governors to prevent a machine from responding to small frequency deviations that are ever present in electrical systems. The use of governor deadbands is widely understood, however often overlooked in power system simulation. Incorporating governor deadbands into transient simulation models has been shown to generate results that better match measured power system events**kou2016**.

Recently, the North American Electric Reliability Corporation (NERC) undertook an initiative to study the degradation of primary frequency response in the eastern interconnection**nercFRI2012**. The initiative culminated in an Industry Advisory bulletin recommending a maximum deadband setting of ± 36 mHz for generators intended to supply primary frequency response. The recommendation was later adopted by the Federal Energy Regulatory Commission (FERC) in FERC Order 842, which mandates that utility pro forma Interconnection Agreements include the deadband limitation**FERCxxxx**. The NERC advisory, and the body of work leading to the advisory, also document a lack of accurate modeling related to governor deadbands, and commensurate accuracy issues when using classical transient stability models for studying primary frequency response issues.

Transient stability simulation is useful for the study of primary frequency response, however there is little understanding of the impact of governor deadbands on valve travel of individual generating units. Do deadbands really reduce overall valve travel? By how much? Does a deadband on one unit increase overall valve travel of other units within the Balancing Authority (BA)? Outside of the BA? It is difficult to answer these questions within the framework of a classical transient stability simulation due to the relatively short time frame of focus. These questions require the development of a simulation environment capable of simulating tens of minutes to hours. Long-term dynamic (LTD) simulation software focusing on governor dynamics was proposed in **AGCCresap**, **DonnellyVoltageControl**, **Stajcar** and others, but has not been standardized nor fully developed.

In this work, the authors take the LTD simulation concept further to enable the study of governor deadbands over a much longer simulation duration than can be reasonably accomplished with classical transient stability simulation. This paper explores the impact of governor deadbands using a novel LTD simulation environment based on the static models and nonlinear solver of GE Energy's Positive Sequence Load Flow (PSLF)**PSLFUserManual**, coupled with an external ODE solver and related dynamic data. Valve travel as a metric for comparing the impact of various deadband scenarios is proposed. Section II describes the LTD simulation environment used to perform the studies while Section III discusses governor and deadband modeling within the simulation environment. In Section IV, the LTD simulation is validated against mature transient stability simulation. Finally, Section V presents some initial results demonstrating the viability of the proposed valve travel metric and Section VI offers conclusions.

II. LONG-TERM DYNAMIC SIMULATION TECHNIQUE

Time-sequenced power flow (TSPF) is a method for LTD simulation proven to generate useful results**DonnellyVoltageControl**. The basic idea behind TSPF is to solve a power flow, represent system dynamics of interest independent of the power flow solver, 're-seed' the power flow with new values, and repeat. A python based simulation software, Power System Long-Term Dynamic Simulator (PSLTDSim), has been developed to perform LTD simulations using TSPF. PSLTDSim has the ability to calculate system frequency, perform governor dynamics, model automatic generation control (AGC), and insert step, ramp, and noise type perturbances into a power system.

A. Simulation Assumptions and Simplifications

Due to the relatively large time steps of 1 second used with TSPF, numerous assumptions can be made. Ideal exciters were assumed as modern exicters are typically fast enough to maintain reference voltage under stable conditions. Intermachine oscillations were ignored since the time resolution used is not fine enough to capture these phenomena.

Simplifications of transient stability models are used in PSLTDSim. The only parameters required to model a generator are the machine's rated MW, the machine's MVA base, and machine inertia. Additionally, a deadband modified tgov1 governor model, Fig. 1, was created to model system governors.
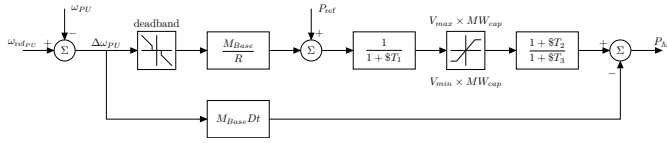
Fig. 1. Block diagram of modified tgov1 model.

B. Modeling the System-Wide Frequency Response

Instead of frequency being calculated for every bus, a combined swing equation is used to model only one system frequency. As shown in (1), accelerating power from the entire system, as well as total system inertia $H_{PU,sys}$, is used to calculate $\dot{\omega}_{sys}$.

$$\dot{\omega}_{sys} = \frac{1}{2H_{PU,sys}} \left(\frac{P_{accPU,sys}}{\omega_{sys}} - D_{sys}\Delta\omega_{sys} \right) \quad (1)$$

C. Distribution of Accelerating Power

In a system with N generators, total system accelerating power is calculated by

$$P_{acc,sys} = \sum_{i=1}^{N} P_{m,i} - \sum_{i=1}^{N} P_{e,i} \quad (2)$$

where $P_{m,i}$ is mechanical power and $P_{e,i}$ is electrical power of generator i.

System accelerating power is distributed to all generators in the system according to machine inertia as

$$P_{e,i} = P_{e,i} - P_{acc,sys} \left(\frac{H_i}{H_{sys}} \right) \quad (3)$$

where H has units of $MW \cdot s$.

The new value for $P_{e,i}$ is used in the next power flow solution for each generator. If the difference between expected and resulting power supplied by the slack generator is larger than a set slack tolerance, the difference is redistributed according to (3) until the resulting difference is below the slack tolerance, or a maximum number of iterations take place**Stajcar**.

III. Implementation of Deadbands

FERC Order 842 specifies for governor droop and deadband settings of 5% and a maximum of 36 mHz respectively**ferc2018**. Practical implementation of the terms of the Interconnection Agreement is left to generator operator. Several types of deadbands are currently used in practice.

A. Types of Deadbands

Fig. 2 presents implementations of deadbands that meet FERC specifications. If a governor has no deadband, a change in output power is requested for any frequency deviation. A step deadband ignores any frequency smaller than the setpoint $\pm db_1$ and then steps to meet the set droop curve. A no-step deadband pushes the original droop curve away from the nominal frequency allowing for the droop curve to cross zero at $\pm db_2$ but never return to the step or no deadband droop curve. A non-linear deadband is introduced that linearly increases from $\pm\alpha$ to $\pm\beta$, after which it follows the original droop curve.
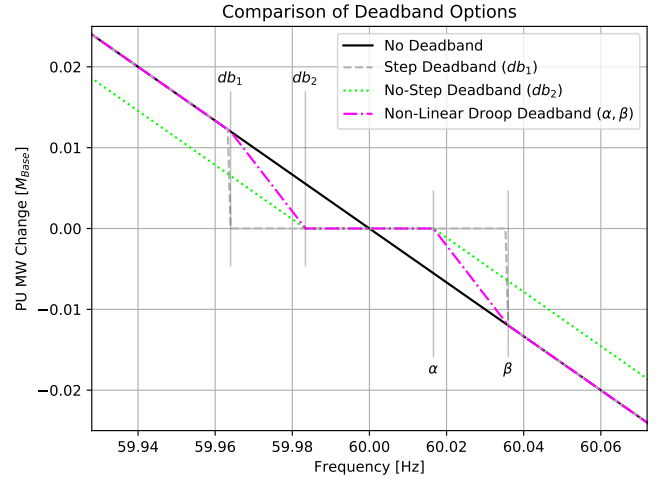

Fig. 2. Different types of deadbands.

IV. Simulation Validation

To validate the chosen simulation approach, identical system perterbations were simulated in both the PSLF Dynamic Subsystem (PSDS), a classical transient stability simulation environment, and PSLTDSim. Frequency comparisons were used to validate the single system frequency assumption calculated by PSLTDSim. Comparisons of the mechanical power of governed generators were used to validate governor action.

Comparison of frequency data from PSDS to LTD was simplified by calculating a single weighted PSDS frequency f_w based on generator inertia. In a system with N generators

$$f_w = \sum_{i=1}^{N} f_i \frac{H_{PU,i}M_{base,i}}{H_{sys}} \quad (4)$$

$$\text{where } H_{sys} = \sum_{i=1}^{N} H_{PU,i}M_{base,i}. \quad (5)$$

A. The MiniWECC System

The power system used for validation and valve travel experiments, the 'miniWECC' shown in Fig. 3, is a 120 bus 34 generator system created in PSLF. The governored machines in the miniWECC were modeled with the tgov1 governor, which enabled easier validation. Further details about the creation and use of the miniWECC may be found in **trudnowski2012**, **sandia2015**, **RJminiWECC**.
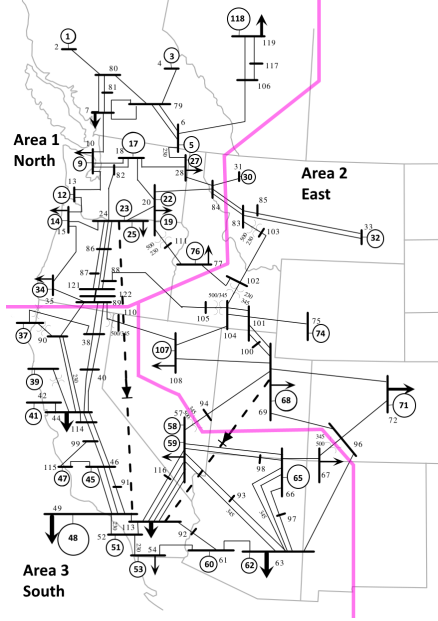

Fig. 3. MiniWECC system adapted from **RJminiWECC**.

1) Load Step Results: A 400 MW load step at $t = 2$ seconds was used for validating the performance of the PSLTDSim. As shown in Fig. 4, all individual PSDS frequencies begin to oscillate after the perturbation while the weighted PSDS frequency appears to follow the general center of oscillation. The LTD system frequency is less oscillatory than the weighted frequency with only minor differences between the two. Fig. 9 quantifies these frequency differences.

When comparing mechanical power in Fig. 6, large MW differences can be seen, however, the percent difference data in Fig. 7 shows results less than 5% max difference, and an average percent difference of less than $\approx 0.5\%$.

2) Load Ramp Results: A second set of validation results, using a 40 second 400 MW load ramp, were also generated. Figs. 8-9 show frequency of LTD being within 1.5 mHz of PSDS. Fig. 10 shows mechanical power differences of less than ± 10 MW or, as Fig. 11 shows, 1% difference max.

B. Validation Summary

The validation results show that PSLTDSim accurately captures long term power system dyanmics. The step test results show that PSLTDSim cannot replace classical transient stability simultion for the study of large, short-duration transient events, however repeated small perturbations are modeled with acceptable deviation from transient simulation methods.
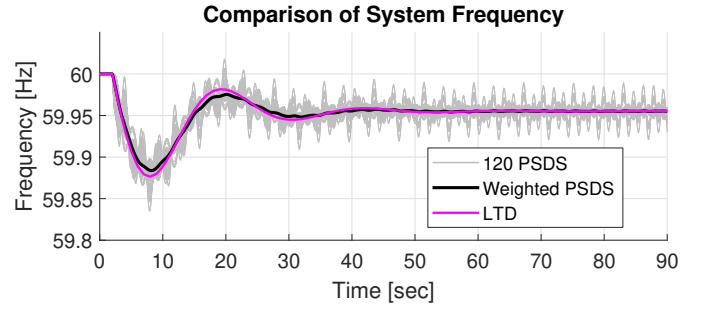

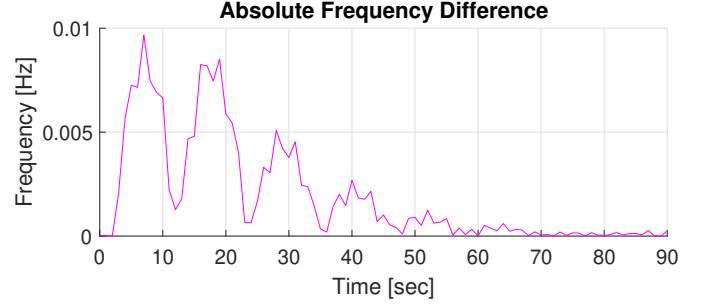Fig. 4. Comparison of frequency during load step.

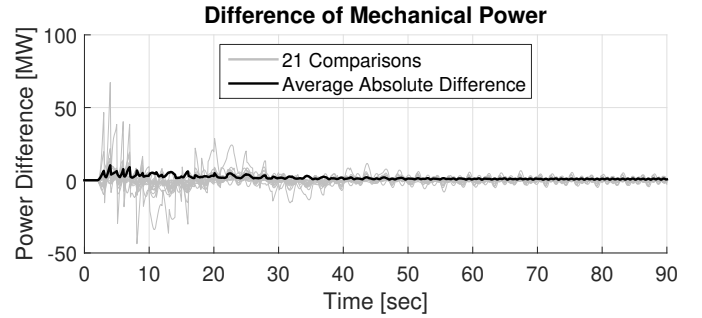Fig. 5. Absolute difference of weighted frequency during load step.

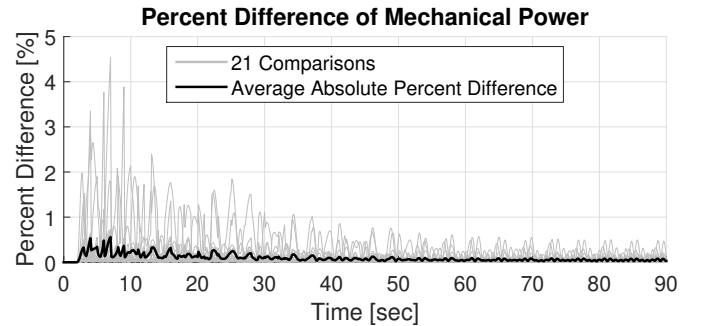Fig. 6. Difference of mechanical power during load step.

Fig. 7. Percent difference of mechanical power during load step.

V. INITIAL RESULTS

To assess long-term impacts of governor deadbands, thirty minutes of random load noise was applied to the study system where every governor in the system had an identical deadband.
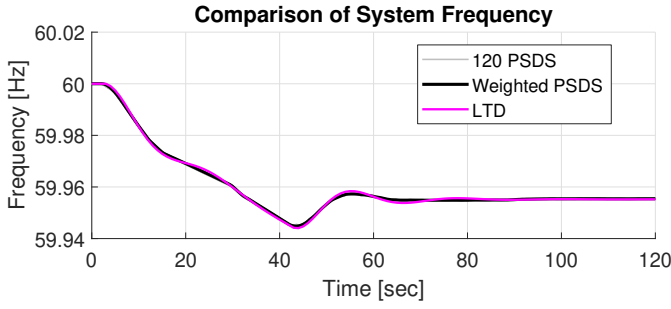
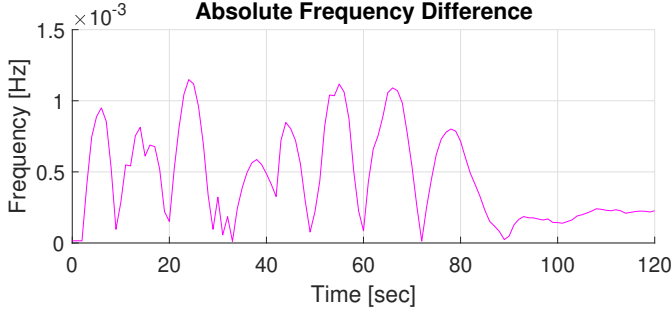Fig. 8. Comparison of frequency during load ramp.

Fig. 9. Absolute difference of weighted frequency during load ramp.
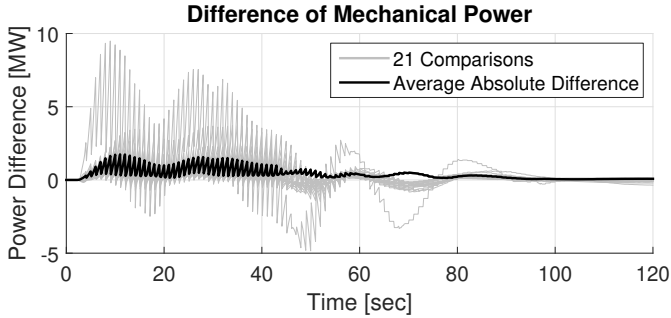

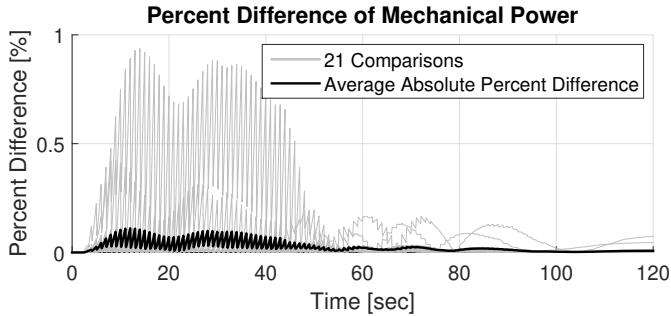Fig. 10. Difference of mechanical power during load ramp.

Fig. 11. Percent difference of mechanical power during load ramp.

Each type of deadband shown in Fig. 2 was simulated. An experiment was also conducted to explore partial acceptance of the NERC recommendations presented in **nercFRI2012**. [MKD NOTE: I don't know what this means.] While PSLTD-

Sim can model AGC, it was not enabled for these simulations. Approximately 20% of generation was governor-enabled, and all governors had droop settings of 5%.

A. System Noise Injection

At every time step, noise is injected into each load $P_{L,i}$ in the system according to

$$P_{L,i} = P_{L,i}(1 \pm N_Z Rand_i) \qquad (6)$$

where N_Z represents the maximum amount of random noise to inject as a percent, and $Rand_i$ is a randomly generated number between 0 and 1 inclusive. The decision to add or subtract noise is chosen by another randomly generated number. As described in **AGCCresap**, (6) creates random walk behavior in load value that is representative of real power systems.

B. Noise Simulation Results

N_Z was set to 0.03 for all simulations. The change in system loading caused by the added noise is shown in Fig. 12. Fig. 13 shows the resulting system frequency for each type of deadband. The step deadband holds frequency almost exactly on the set deadband except when system loading decreases during minutes 7-11. The other deadband options maintain system frequency near their respective mHz setting until loading increases beyond a point near minute 17.
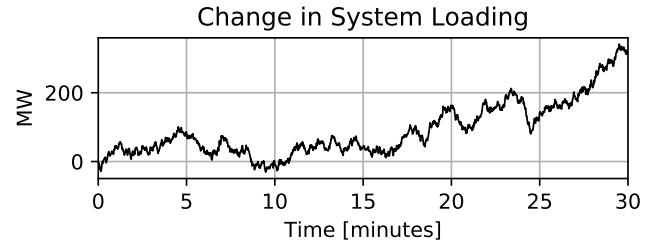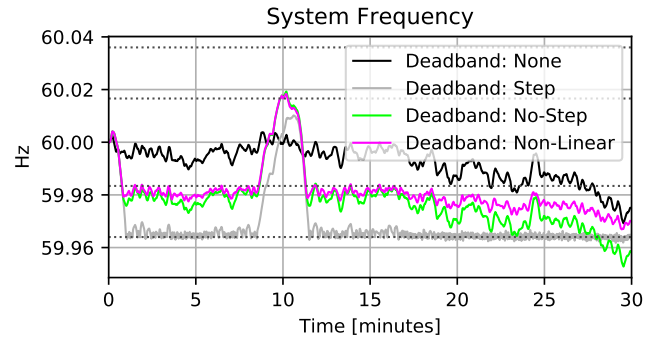

Fig. 12. Change in total system loading.

Fig. 13. System frequency response of various deadband scenarios.

The first three minutes of a single generators valve travel are shown in Fig. 14 to compare how different deadbands affect movement. A step deadband will send pulse train-esq

control signals to the governor valve when system frequency is oscillating over the deadband. These repeated control pulses greatly increase valve travel over the more linear deadband options.
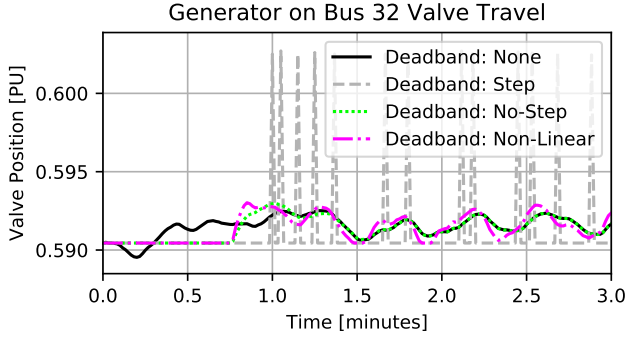

Fig. 14. Valve movement deadband comparisons.

Table I summarizes the valve travel for each generator in the system over the entire 30 minute simulation. A step type deadband has the largest total travel while the no-step deadband has the least.

TABLE I
TOTAL VALVE TRAVEL FOR VARIOUS DEADBAND SCENARIOS.

| | Valve Travel [PU] | | | | |
Generator	No DB	Step	No-Step	N-L Droop	No-Step Alt DB
17	0.16	7.48	0.15	0.23	0.19
23	0.16	7.48	0.15	0.23	0.19
30	0.16	7.48	0.15	0.23	0.19
32	0.16	7.54	0.15	0.23	0.19
107	0.16	7.54	0.15	0.23	0.19
41	0.15	6.44	0.14	0.23	0.06
45	0.15	6.44	0.14	0.23	0.06
53	0.16	7.54	0.15	0.23	0.06
59	0.15	6.44	0.14	0.23	0.06
Total:	1.41	64.38	1.32	2.07	1.19

C. Partial Acceptance Simulation Results

To test partial acceptance of NERC deadband recommendations, all area deadbands were set to the no-step variety, but two of the three areas had a deadband of 16.6 mHz while the third was set to 36 mHz. The resulting system frequency is shown in Fig. 15.

As expected, the area with a larger deadband doesn't respond until after frequency drops below its deadband while the areas with smaller deadbands work to maintain frequency. Individual valve travel for each generator is shown in Table I under the 'No-Step Alt DB' column, and Fig. 16 shows average valve travel over time for each area. In this case, the governor valves with a smaller deadband travel three times more than those with a larger deadband.
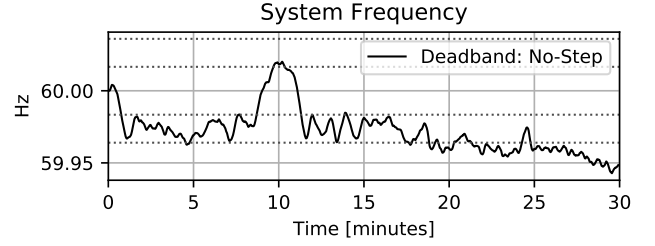

Fig. 15. System frequency response to 0.03% load noise where no-step deadbands have different area settings.
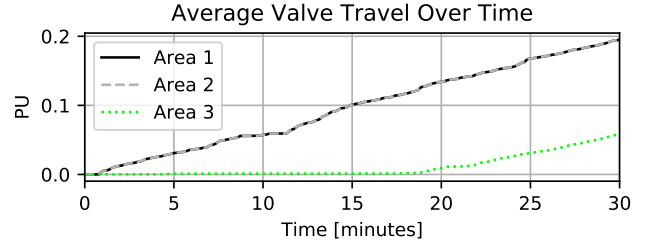

Fig. 16. Average valve travel by area.

VI. CONCLUSION

This work demonstrates that deadband configurations play a large role in dictating valve travel. Counterintuitively, a step deadband can lead to vastly increased valve travel compared to other, more linear, options. Smaller deadbands, as recommended by NERC, can reduce valve travel and help regulate frequency if adopted interconnection-wide. If only partial adoption of recommendations is made, machines with smaller deadbands will respond more than machines with larger deadbands.[MKDNOTE: I want to talk about this statement.] Further, this work demonstrates the need for a simulation environment that can capture long-term power system dynamics with appropriate static and dynamic models. The 'sequence of power flows' approach to long term dynamic simulation is shown be be most useful. Future work in this area will focus on using the cumulative valve travel metric to study and optimize various governor and AGC control strategies.