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Research Paper

An Analysis of Problems with Model-Based Time-Delay Compensation Methods

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ABSTRACT:
The utilization of digital microprocessors for the operation of grid-connected inverters has been made feasible by recent developments in the field of digital signal processing. Conversely, the phase latency that results from temporal delays serves as an obstruction to the successful implementation of digital technologies. The inverter controller's stability and robustness are assessed in the context of this phase latency. This work offers a comprehensive examination of time-delay compensation methods for both model-free (MF) and model-based (MB) inverter controllers in the context of grid connections. In the majority of instances, proportional-integral and proportional resonance controllers are employed in MF techniques. Furthermore, certain strategies are implemented with the objective of reducing the duration of the delay. These techniques are among the most frequently employed control techniques for MB. This article offers a comprehensive account of numerous comparable strategies that have been extracted from the existing body of research in order to mitigate delays, in addition to a discussion of critical issues related to the MF and MB processes. This study presents a theory regarding the current method in use and proposes a hybrid technique that integrates the MF and MB procedures. Additionally, this investigation establishes a foundation for future research.
Keywords: *Issues with Model-Based, Time Delay, Compensation Methods, Digital Signal Processing.*

I. INTRODUCTION

Traditional power systems have lately been experiencing a shift inside their routine operations that is transforming to meet the increasing global demand for electricity. This means that networks need to be liberalized to include renewable energy sources like wind and solar if we are to keep up with the ever-increasing global demand. It is possible that these renewable energy sources might contribute significantly to the main grid's electrical supply if they are fully gathered and used in a regulated setting. Dispersed generation (DG) is being used to meet this need. This approach employs grid-connected inverters, which are power electronic equipment, to systematically link DG systems, creating a microgrid-like configuration. Connecting separate distributed generation (DG) units helps make the system more adaptable, which is good for optimizing, protecting, securing, and controlling power quality, among other things. Safety during operation, power quality, and islanding protection are all established by new and stringent criteria in [2]. Because there are unique challenges encountered by devices that interact with the grid, especially under less-than-ideal conditions, this is the case [1]. Recent developments, such as real-time controllers with the ability to execute complex control algorithms and power electronic devices with high power management and rapid switching capabilities [3], have brought these interconnection issues into the spotlight, leading to a surge in research efforts. The control loop latency and delays during grid-connected and islanding modes transitions are among the many issues with real-time controllers. The capacity of a material system to react to an external stimulus with a postponed effect is known as time-delay [4]. The ability of the system to respond describes this capability. There is always some degree of latency involved in the transmission of energy or control signals from one point to another. Propagation describes this lag. The propagation delay is proportional to the speed of the sent signal and the properties of the medium it is passing through. during the inverter's digital control loop experiences a considerable delay, either during switching between grid-connected and island modes or during design and implementation, it complicates controller operations. As a result, irregularities in voltage and frequency become much more noticeable. A modest delay may be effectively remedied using a range of compensatory strategies. Inverters that are linked to the grid may employ LCL filters and either an inner-loop or an outer-loop topology with a voltage, current, or direct power controller, or a mix of these. It is also possible to use these controllers in a different order. Due to its accurate current tracking, ample control bandwidth, and fast transient response, inner current control has been used in a considerable deal of research. Conversely, voltage source inverters (VSIs) use the currently utilized controller to allow the inverter to operate as a current amplifier within the current loop bandwidth [5]. In contrast, the voltage controller ensures that power flows through the system by protecting it from grid and input source disruptions in an outer-loop configuration. Regardless, with digital solutions in particular, the control loop introduces a time delay that limits the control bandwidth of the existing controller. Another innovation that has come about because of developments in digital signal processing is the use of digital microprocessors to control grid-connected inverters [6]. The digital implementation offers more control flexibility, faster system reprogramming, and higher reliability than the analog control. Among the many drawbacks of this digital technology, the most glaring is the phase lag brought about by the control loop's temporal delay. This lag will be much more noticeable once more control loops are installed. A thorough comprehension of the primary causes of time-delay in the control loop of a grid-connected inverter is necessary before exploring the several commonly used time-delay compensation solutions. Key causes of digital controller deployment delays include the time needed for calculation, the zero-order hold effect of digital pulse-width modulation, and the sampling and updating of voltage and current data for control reasons. This suggests that obtaining high performance when the control loop is experiencing large delays in time can be somewhat difficult. This causes the controller to have a low-gain crossover frequency, which in turn reduces transient responsiveness, increases overshoot (from an insufficient phase margin), and decreases control bandwidth.

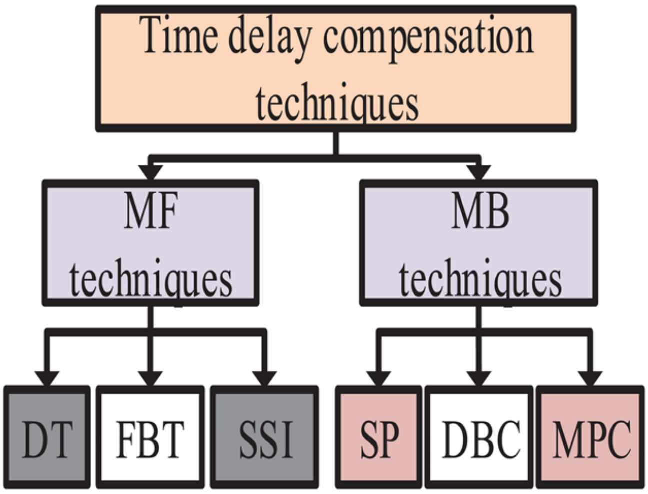

Fig 1 : Common time-delay compensation techniques for grid connected inverter

The controller's overall performance will drop and there will be a lot of unsavoury side effects, such instability. The employment of compensators, which reduce or remove delays, may decrease or eliminate these effects totally. Numerous time-delay compensation schemes have been documented in academic journals. The use of models, or lack thereof, is one criterion for classifying these methods [6]. The two main categories are shown in Figure 1. Maximal likelihood (MF) methods are less precise, but they are insensitive to model quality. However, maximum likelihood (MB) based approaches are more accurate, although they are very model dependent. Smith predictors (SP), modified Smith predictors (MSP), deadbeat controllers (DBCs), and model predictive controllers (MPCs) are among the several types of MB time-delay compensation systems. The filter-based technique (FBT), the shifting the sampling instant (SSI) of the control variable, and the damping technique (DT) were among the MF techniques employed for comparison. Research in this area aims to highlight existing problems and potential solutions with the goal of reducing the effect of time delay in the control loop of grid-connected inverters. An additional noteworthy contribution is that it paves the way for future research into the topic of delay reduction.
Deadbeat controller (DBC) and model are also provided.

II. PROBLEMS WITH MODEL-BASED TIME-DELAY

Therefore, the controller lacks the resilience necessary to fulfill the grid connection standard and industrial code owing to the intermittent nature of the major source of energy in distributed generating units. The SP and MSP approaches for time-delay compensation are created utilizing P, PI, and PR controllers. Reduced stability and precision in handling time-varying signals, slow reaction as a result of rapid disturbances, sensitivity to controller gain and parameter changes, and poor disturbance ejectionability are the primary downsides of this technique. This approach is much less appropriate for grid-connected inverters as a result of these limitations. At the same time, the database has problems with one sample delay, susceptibility to model errors, parameter mismatches, noise on thesensed variables, and unexpected disturbances (from the DC-link voltage and grid impedance).

There have been several topologies proposed in order to circumvent the constraints of DBC. Some examples of these topologies include the double-, quadruple-, and multi-sampling and updating approaches that are used to circumvent the one-sampling delay. An adaptive model is constructed to relax parameter sensitivity and parameter mismatches, a filter is put in series with the sensing devices to filter the noise, and a disturbance estimator is utilized to reject disturbances that were not expected. However, some research works have incorporated two distinct controllers in their design. For example, the DBC is used in the inner current or power loop, while the outside loop is controlled by other kinds of controllers such as the PI. In certain circumstances, the DC bus is believed to be an ideal constant DC voltage source, and there is no outer-loop control.

III. SUMMARY OF RESULTS

As an additional point of interest, several research studies have assumed that the influence of time delay on the controller is insignificant. Consequently, its influence on the phenomenon of resonance frequency shift and the stability of the system was determined. There is a summary of such literature in Table5. The assumption of the perfect DC voltage supply and the insignificant influence of time delay in the design of the digital controller, on the other hand, leads to a reduction in the system's performance and a lack of resilience in the controller against disturbances. On the other hand, several study methodologies have taken into consideration the fact that renewable energy sources cannot be presumed to be an ideal constant voltage source. Because of this, they took into consideration the impact of time delay in their study work, where they found that the delay was significantly decreased by using several strategies that are outlined in Table 1.

Table 1: Summary of DBC considering time-delay effect

S/No	Author	Filter type	PWM update	Inner current loop controller	Outer control loop	Control parameter	Feedback	Feed-forward	Technique
1	[5]	L	Single	DBC	N/A	*I*	SL	N/A	TNE
2	[20]	LC	Double	DBC	PI	*I*, *V*	DL	N/A	DSDU/FBT
3	[94]	LC	Single	PI	N/A	*I*	SL	N/A	SO
4	[52]	L	Single	DBC	N/A	*I*, *V*	SL	N/A	TNE
5	[84]	N/A	Single	1. LP 2. SP	N/A	*I*	SL	N/A	SPT
6	[85]	L	Single	SP	N/A	*I*, *V*	SL	N/A	SPT
7	[95]	L	Multiple	DBC	N/A	*I*, *V*	N/A	N/A	MSMU
8	[59]	L	Multiple	DBC	N/A	*I*, *V*	N/A	SL	MSMU
9	[71]	LC	Single	DBC	ANN	*I*, *P*, *Q*	SL	N/A	NCO
10	[96]	LC	Single	DBC	DBC	*I*, *V*	ML	DL	SO
11	[97]	LCL	Single	DBC	N/A	*I*	SL	SL	TNE
12	[98]	L	N/A	N/A	DB	*P*, *Q*	SL	N/A	TNE

However, there are some research works that only considered the time delay effect, but assumed an ideal constant DC source. For example, the research in [5] neglected the outer-loop voltage control, which may have severe effects on the overall performance of the controller in the presence of any kind of disturbance that was not anticipated. At the same time, two study works took into consideration both the non-ideal character of the DC sources and the time-delay effect. One example of this is the research that was conducted, in which a direct current controller (DBC) was used for the inner current control, and an artificial neural network (ANN) was utilized for the outer power-loop control. The grid voltage sensorless interface method that was devised was inherently self-commissioning and self-tuning, and it assured optimum performance of the system with decreased time-delay. This study was successful in achieving its goals, and the findings were positive. Nevertheless, the outcome was characterized by a delay that occurred during a single sample, which may be further decreased by using a strategy that involves double or multi-loop updating of the time delay. Furthermore, the impact of grid impedance was not taken into consideration in this study, which may provide a challenge to the system's stability.

In a different piece of study, the author explored a two-cascaded-loop architecture, in which DBC was implemented in both the inner current loop and the outer voltage loop. A disturbance observer was used in order to reject load current disturbances, and a state observer was utilized in order to reduce the amount of time that the delay continued. As a consequence of this study endeavor, positive outcomes were accomplished. The state observer that was used, on the other hand, was sensitive to changes in the system parameter, in addition to the inherent modeling error and the significant prediction error [12]. Additionally, the off-grid system was used to implement the findings of this study. Therefore, the stability has not been explored up to this point when it is applied to grid-connected inverters.

IV. CONCLUSIONS

For those interested in the analytical work on grid-connected inverter control loops using time-delay compensation approaches, this paper offers a succinct summary. Due to its relative simplicity and average performance, MF was chosen as the optimal approach in this analysis, despite issues with system stability in inverter-side and grid-side topologies. This paper examines both MF and MB, two models of controller-dependent systems. Here we will compare the models. When linked to an unreliable grid or otherwise interfered with, these controllers would not be able to do their jobs. Many methods have been suggested to improve system stability and decrease time-delay using fewer and simpler controllers; nevertheless, these controllers may lack robustness. Following the assessment of model-based approaches, the Smith predictor and the modified Smith predictor were the first approaches used to achieve time-delay balance in traditional PID controllers. The first use of the Smith predictor led to this. This approach is not as helpful for grid-connected inverters as their controllers can't manage time-varying signals or provide sufficient disturbance rejection. However, DBC's popularity has grown due to its many advantageous features, such as its ability to quickly monitor current, reject disturbances, compensate for time delays, and have zero steady-state error. This strategy is classified into two groups in this article according on whether the time delay effect is considered during controller design. Several experiments of time delays were conducted under the premise that the DC-link and grid electricity were continuous. The outer loop was not a part of the controller's design. This paper recommends a combination of DBC and many MF time-delay compensation approaches to researchers, including using DBC in the inner loop and MPC in the outer loop, and applying fuzzy logic in the outer loop using QSQU. This hybrid controller has a low total harmonic distortion, a decent output current, a rapid transient and dynamic response, and a short control-loop time-delay; using an LCL output filter ensures system stability. The literature study indicates that these controls are absent.

REFERENCES

[1]. Control and protection of power electronics interfaced distributed generating systems in a customer-driven microgrid, by Peng, F.Z., et al. According to the IEEE Power and Energy Society General Meeting, held in Calgary, Alberta, pp. 2009, pages 1–8

[2]. Blaabjerg, F., et al.: Overview of control and grid synchronization for distributed power generation systems. IEEE Trans. Ind. Electron. 53(5), 1398–1409 (2006)

[3]. Carrasco, J.M., et al.: Power-electronic systems for the grid integration of renewable energy sources: A survey. IEEE Trans. Power Electron. 53(4), 1002–1016 (2006)

[4]. Zhong, Q.C.: Recent results on robust control of time-delay systems. In: Proceedings of the 7th World Congress on Intelligent Control and Automation. Chongqing, China, pp. 301–306 (2008)

[5]. Ibrahim Mohamed, Y.A.R., El-Saadany, E.F.: An improved deadbeat current control scheme with a novel adaptive self-tuning load model for a three-phase PWM voltage-source inverter. IEEE Trans. Ind. Electron. 54(2), 747–759 (2007)

[6]. Lu, M., et al.: Graphical evaluation of time-delay compensation techniques for digitally controlled converters. IEEE Trans. Power Electron. 33(3), 2601–2614 (2018)

[7]. Cao, B., Chang, L.: Robust predictive current control for grid-connected VSIs with compensation for time-delay effect and uncertain system disturbances. In: IEEE Energy Conversion Congress and Exposition ECCE 2015. Montreal, QC, pp. 2698–2702 (2015)

[8]. Wang, X., et al.: A robust grid-voltage feedforward scheme to improve adaptability of grid-connected inverter to weak grid condition. IEEE Trans. Power Electron. 36(2), 2384–2395 (2020)

[9]. Corradini, L., et al.: Advantages of the symmetric on time modulator in multiple-sampled digitally controlled DC-DC converters. IEEE Trans. Power Electron. 2, 1974–1980 (2007)

[10]. Corradini, L., et al.: High-bandwidth multisampled digitally controlled DC–DCconverters using ripple compensation. IEEE Trans. Ind. Electron. 55(4), 1501–1508 (2008)

[11]. Fujita, H., A single-phase active filter using an H-bridge PWM converter with a sampling frequency quadruple of the switching frequency. IEEE Trans. Power Electron. 24(4), 934–941 (2009)

[12]. Ma, J., et al.: Multisampling method for single-phase grid-connected cascaded H-bridge inverters. IEEE Trans. Ind. Electron. 67(10), 8322–8334 (2020)

[13]. Odavic, M., et al.: Multi-sampled carrier-based PWM for multilevel active shunt power filters for aerospace applications. In: IEEE Energy Conversion Congress and Exposition. Phoenix, AZ, pp. 1483–1488 (2011)

[14]. Jinming, X.U., et al.: An improved inverter-side current feedback control for grid-connected inverters with LCL filters. In: 9th International Conference on Power Electronics- ECCE Asia. IEEE, Piscataway, NJ, Vol. 106(10), pp. 984–989 (2015)

[15]. Haider, M.A.R., et al.: Robust current controller for grid-connected voltage source inverter. In: IEEE 8th International Symposium on Power Electronics for Distributed Generation Systems, PEDG. Brazil, pp. 1–7 (2017)

[16]. Ahmadi, A.H., Nikravesh, S.K.Y.: Robust smith predictor (RSP). In: ICEE2016:The24thIranianConferenceonElectrical Engineering. Iran, Vol. 4, pp. 1510–1515 (2016)

[17]. Kumar,S.: Modifiedsmithpredictor design for networked control system with time-delay. In: International Conference on Energy, Power and Environment: Towards Sustainable Growth. Meghalaya, India, pp. 1–5 (2015)

[18]. Sajadian, S., Ahmadi, R.: Model predictive control of dual-mode operations Z-source inverter: Islanded and grid-connected. IEEE Trans. Power Electron. 33(5), 4488–4497 (2018)

[19]. Nguyen-Van, T., et al.: Stability of FPGA based emulator for half-bridge inverters operated in stand-alone and grid-connected modes. IEEE Access 6, 3603–3610 (2018)

[20]. Koleff, L., et al.: H-infinity current control of the LC coupled voltage source inverter. In: IEEE Energy Conversion Congress and Exposition, ECCE. Cincinnati, OH, pp. 5347–5354 (2017)

[21]. Skogestad, S., Postlethwaite, I.: Multivariable feedback control—Analysis and design. IEEE Control Syst. 27(1), 80–81 (2007)

[22]. Buso, S., et al.: Dead-beat current controller for voltage-source converters with improved large-signal response. IEEE Trans. Ind. Appl. 52(2), 1588–1596 (2016)

[23]. Buso, S., et al.: Analysis and experimental characterization of a large bandwidth triple-loop controller for grid-tied inverters. IEEE Trans. Power Electron. 34(2), 1936–1949 (2019)

[24]. Judewicz, M.G., et al.: Inverter-side current control of grid-connected voltage source inverters with LCL filter based on generalized predictive control. IEEE J. Emerg.Sel. Top. Power Electron. 6(4), 1732–1743 (2018)

[25]. Mattavelli, P., et al.: Predictive digital control of power factor pre regulators with input voltage estimation using disturbance observers. IEEE Trans. Power Electron. 20(1), 140–147 (2005)

[26]. Castelló, J., et al.: A robust predictive current control for three-phase grid connected inverter. IEEE Trans. Ind. Electron. 58(8), 3537–3546 (2009)