Startup Implementation in Universal Power Electronics Interface with Dual-Standard Output for DC Microgrid Applications

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***Abstract*—This work studies soft start implementation in the universal power electronics interface (UPEI) with dual-standard output for dc microgrid applications (350/700V). It is based on a series-resonant converter designed to operate with quality factors below unity at a constant switching frequency. It must pre-charge output capacitors to prevent inrush current and false triggering of protection devices when connecting to a dc microgrid. This work proposes a soft start implementation method to limit the inrush currents by implementing a simple PI-based topology morphing control. Also, it requires an extra safety switch added between the output capacitors of the converter and the output dc port. This paper compares converter startup operation with/without the soft start by initial charging of its output capacitor. The verification of the proposed strategy has been performed using PSIM.**

Keywords—soft start, dc-dc converter, inrush currents, series-resonant converter, dc microgrid, duty cycle control

I. Introduction

Over the past decade, power electronics interfaces based on resonant converters have emerged as a highly promising technology for a wide range of applications. These include electric vehicles (EVs), renewable energy systems such as solar power and battery storage, as well as critical advancements in the aviation industry [1]. The growing interest in resonant converter-based solutions is driven by their potential to enhance efficiency, reduce switching losses, and improve overall system performance across these diverse sectors [1-3]. However, the resonant topologies are susceptible to significant resonant inrush currents during startup, which can impose substantial electrical stress on the power devices [3]. These high inrush currents not only lead to excessive voltage and current surges but also pose a serious risk of damaging critical components, ultimately compromising the reliability and longevity of the converter.

Applying dc-dc converters in dc microgrid applications makes this issue even more challenging, as the corresponding solid-state protection could react to overcurrent transients in less than 10 μs [4]. Addressing these challenges is crucial for ensuring stable and efficient performance of resonant converters in dc microgrids [5]. Implementation of a soft start mechanism in dc-dc converters is pivotal for mitigating inrush currents to make them compatible with the requirements of dc microgrids. This could be achieved by ensuring a controlled voltage ramp-up across the output capacitor during the converter's initialization phase [6].

A soft start mechanism generally involves gradually increasing the duty cycle or frequency of the converter switching components, thereby controlling the rate at which energy is transferred from the input to the output before connecting to the sensitive source/load [7]. In short, charging the converter's filter or dc link capacitors to match the dc bus voltage before connection is referred to as pre-charging, and starting the converter while connecting to the sensitive system without inrush current is the soft start. This minimizes stress on the converter's components, such as the resonant capacitor(s), which are particularly vulnerable to high surge currents and voltages. Series-resonant topologies are known for their simplicity, consistent switching frequency, soft-switching capabilities, and expansive input voltage range, rendering them well-suited for diverse applications [8]. Their resonant capacitors need protective clamping to avoid overvoltages during startup or short-circuit events if no soft start and protection measures are implemented [9], [10].

This paper focuses on the universal power electronics interface (UPEI) proposed in [11]. It is based on the highly reconfigurable topology of the series-resonant dual active bridge [12]. One of its remarkable features is the dual standard output for compatibility with residential 350 V and 700 V dc microgrids, which was verified in [13]. This feature is enabled by the topology morphing control (TMC) that substantially extends the voltage range of the converter. However, a strategy for connecting the converter to a dc microgrid with no inrush current is needed. Typically, the dc link capacitor pre-charging is achieved using the dedicated pre-charging hardware circuit [14], which leads to a rise in component count and cost of the converter.

An example of the dc-link capacitor pre-charging for the CLLLC converter using PI-based frequency control is presented in [9]. The pre-charging or soft start of the converter is either achieved by frequency control or duty cycle control, which is feasible only when the converter either operates in a certain quality factor (Q-factor) range (CLLLC topology) or

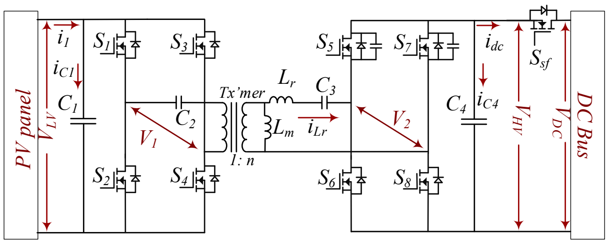


Fig. 1. Universal power electronics interface under study.

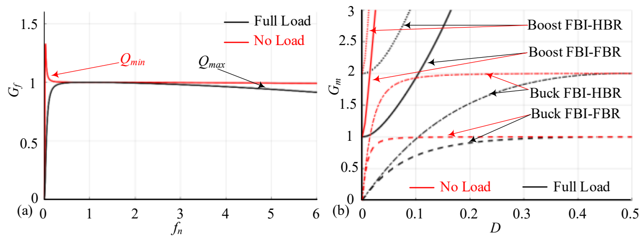


Fig. 2. Normalized voltage gain characteristics with normalized frequency (G_f vs f_n) (a), and duty (G_m vs D) (b) for the UPEI converter.

has a magnetizing to resonant inductance ratio below 6 (LLC topology) [15]. However, startup scenarios with different input voltage conditions are not presented, which is relevant for PV-powered converters connected to a residential dc microgrid. It should be mentioned that some current-fed dc-dc topologies can manage the inrush currents. Still, it may be challenging to isolate the converter or implement a soft stop during maintenance or fault [16,17].

In designs of resonant dc-dc converters with magnetizing to leakage inductance ratio much higher than usual, converter gain control is independent of switching frequency and might need a different idea to achieve soft startup and protection. Such series-resonant dc-dc converters are typically controlled using PWM or PSM at a constant switching frequency [18]. Their control flexibility can be extended to implement the UPIE with a wide input voltage range and dual-standard output using TMC [13]. However, its full compatibility with dc microgrid applications requires the implementation of a robust soft start strategy.

This work aims to develop a simple soft start strategy implemented for SRC-based UPEI for the 700 V dc bus system. The analyses of the topology morphing control for charging the output port capacitor, along with its effectiveness in controlling the inrush current, have been discussed. Additionally, a single switch safety connection between the converter and the 700 V dc bus system has been used, simplifying hardware implementation. Furthermore, the structure of this paper includes a description of the UPEI topology, followed by soft start and control guidelines, and finally, an analysis and validation of TMC-enabled soft start using PSIM simulation is provided.

II. Description of Universal Power Electronics Interface Under Study

A. UPEI Under Analysis

The topology of the series-resonant converter shown in Fig. 1 was first proposed in [12]. It comprises a low-voltage hybrid switching cell (S_1-S_4) at the source side, a transformer, a resonant tank comprising inductance L_r and capacitor C_r, and a high-voltage hybrid switching cell (S_5-S_8) at the dc bus side. The topology morphing control has been implemented for this converter, which exhibits the three viable configurations based on combining full- or half-bridge inverter (FBI/HBI) at the input side and full- or half-bridge rectifier (FBR/HBR) at the output. Considering that this converter is an isolated buck-boost dc-dc converter, it can operate in six different modes, two per configuration. A safety switch (S_{sf}) has been added between the converter and the dc bus to implement soft start. The resonant frequency of this converter can be expressed in terms of resonant inductance and capacitance as,

$$f_r = \frac{1}{2\pi\sqrt{L_r C_r}}, \tag{1}$$

where, L_r is the equivalent leakage inductance of the transformer and C_r is the equivalent series capacitance at the secondary side, including the blocking capacitor C_2 and series capacitance C_3. The UPEI is compatible with two dc microgrid standard voltages, 350 V and 700 V, which have been verified in [13].

Considering that resonant converters generally could be controlled by varying the switching frequency, it needs to be analyzed whether operating this converter with variable frequency control is practical or feasible or whether only duty cycle control is suitable for particular applications. Therefore, the frequency and duty cycle control are reviewed to verify their usability during the startup of the UPEI. This topology features quality factors below unity, and the magnetizing to leakage inductance ratio is much larger than usual, which makes answering this research question not trivial. Hence, these methods are discussed in detail below.

B. Duty Versus Frequency Control

The conventional variable frequency and TMC-based duty cycle control have been analyzed in [15] and [17], respectively. However, they must be reassessed to determine the feasibility of soft start implementation. The individual relationships between normalized voltage gain for normalized frequency, $G_f(f_n)$, and duty cycle, $G_m(D)$, have been plotted in Fig.2(a) and (b), respectively, considering (1)-(3). This represents the behavior of UPEI for the variable frequency and duty cycle control.

The variable frequency control was not useful for controlling the gain at light load or no-load conditions, as can be observed from Fig. 2(a). The normalized converter gain (G_f) in this case is virtually constant, i.e., the switching frequency variations have no real effect on the converter gain. TMC cannot overcome this insufficiency with topology reconfiguration; hence, the variable frequency control is not considered for the soft start implementation.

At the same time, the normalized gain based on duty ($G_m = V_{HV}/nV_{LV}$) shows a strong dependence on the duty cycle D even at no load, as per (3). It could also be observed from Fig. 2(b) that the topology reconfiguration allows the converter to switch between gain ranges. This enables the implementation of a soft start strategy for UPEI using TMC-based duty cycle (D) control described in [12].

$$G_n = G_m . G_f . = G_m . \frac{1}{\sqrt{\left([1+\frac{1}{k}(1-\frac{1}{f_n})]^2+[Q(f_n-\frac{1}{f_n})]^2\right)}} \tag{2}$$

$$G_m = \begin{cases} \left(\beta\left(\frac{1}{4}-\alpha\right)+\sqrt{\beta^2\left(\alpha-\frac{1}{4}\right)^2+2\alpha\beta}\right), & M_1 \\ \frac{1}{2}\left(\beta(1-\alpha)+\sqrt{\beta^2(\alpha-1)^2+8\alpha\beta}\right), & M_3 \\ \frac{1}{(2-\beta)}\left(1+\sqrt{1+4\alpha\beta(2-\beta)}\right), & M_2 \\ \frac{1}{(1-0.5\beta)}\left(1+\sqrt{1+4\alpha\beta(1-0.5\beta)}\right), & M_4 \end{cases} \quad (3)$$

where $\alpha = C_r R_{eq} f_s$, $\beta = 1-\cos(w_r D T_s)$, T_s is the switching period, R_{eq} is the equivalent resistance seen from the secondary winding of the transformer, w_r is the angular resonant frequency, and D is the duty cycle.

It is worth noting that UPEI is based on isolated buck-boost topology. Generally, buck voltage regulation is achieved by changing the modulation of the input side switching cell to limit the active state of the voltage applied to the transformer and, consequently, the resonant tank with a low Q-factor. Contrary to that, boost is implemented by introducing a short-circuit of the transformer secondary winding into modulation of the output side switching cell.

With TMC applied to the converter, the converter voltage gain G_m depends on modes described by (3). Modes M_1 and M_3 correspond to buck mode operation with FBI-FBR and FBI-HBR topology configurations, respectively. Similarly, M_2 and M_4 correspond to boost mode operation with FBI-FBR and FBI-HBR topology configurations, respectively. In the context of soft start, the no load and full load voltage gain curves have been plotted separately for boost and buck modes, as shown in Fig. 2(b) for FBI-FBR and HBI-FBR topology operation. It is worth special attention that the converter in a buck mode can regulate the dc gain down to zero regardless of the topology configuration. This feature could be exploited to implement a soft start strategy. In addition, these modes of operation have already been tested in their steady state for practical applications.

It is logical to use the buck FBI-HBR mode of operation for pre-charging rather than others for two reasons: wider gain range and the possibility of regulating dc gain from zero. After a soft start, normal operations can be carried out with the usual TMC modes, depending on the dc voltage gain of the converter. Hence, there is the possibility to synthesize the pre-charging with soft start of the converter and dc bus system. Pre-charging is considered a part of the soft start strategy. The next section describes the soft start and its control guidelines.

III. Soft Start and Control Guidelines for UPEI

In the context of UPEI, a soft start strategy must fulfill the following conditions: (1) the interfacing component (C_4) between a converter and dc bus charges gradually up to a reference value (i.e., pre-charge stage), (2) the pre-charging should be achieved without any considerable inrush currents in the converter, and (3) soft connection (soft turn on of safety switch S_{sf}) establishment with limited inrush to the dc bus current. This strategy helps establish a smooth connection between the converter and the dc system it connects to. In the given case, it is a rectifier followed by filter capacitor(s) that need to be connected to a dc bus of 700 V. Hence, it is mandatory to charge this capacitor before establishing the power connection using a series safety switch (S_{sf}). The converter would initially see the capacitor C_4 as a load. Hence, the startup circuit will operate with the equivalent resistance

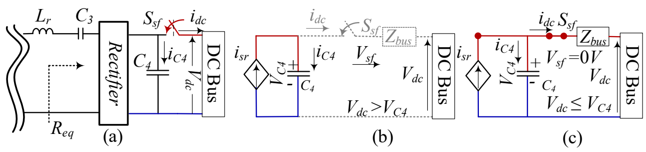


Fig. 3. Simplified (a) secondary side equivalent circuit, (b) pre-charging of C_4 and (c) soft turn-on of S_{sf} switch.

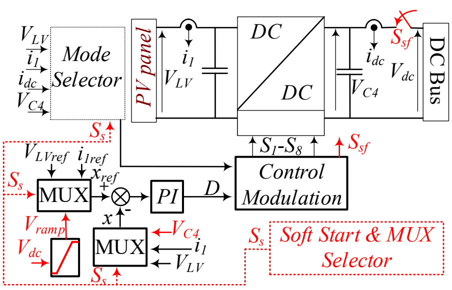


Fig. 4. Simplified control principle for UPEI.

seen at the secondary side of the transformer during the charging of C_4 (Fig. 3(a)), which can be expressed as,

$$R_{eq} = \frac{8}{\pi^2}\cdot\frac{P_o}{V_{dc}^2}\cdot\left(1-e^{-t/\tau_c}\right), \quad (4)$$

where $\tau_c = R_{sp} \times C_4$, represents the charging time constant, R_{sp} includes the series parasitic resistance of the secondary rectifier and ESR of C_4. Fig. 3(b) represents the startup condition when the capacitor C_4 is gradually charged from a controlled power source, i.e., the converter operating with TMC, while being disconnected from the dc bus. At the same time, Fig. 3(c) represents the soft turn-on of S_{sf} after this steady-state operation can be carried out to transfer the power to the dc bus.

A. Soft Start with Buck FBI-FBR Mode

Mode-M_1: (buck FBI-FBR mode): This mode can be used when $0 \le G < 1$. Fig. 5(a) shows the major waveforms of the system under test for $V_{LV} = 60$ V. It can be observed that the charging of the capacitor occurs gradually during the startup mode, which is exactly comparable to the gain versus duty cycle plot in Fig. 2(b). Since the normalized dc gain starts from zero, the maximum inrush dc current is limited to 0.4 A. Due to a low sensitivity to the phase shift angle, this buck mode has smoother control dynamics than the boost modes. However, the gain is limited to unity gain only. Similarly, Mode-M_3 (buck FBI-HBR mode) can be used for $0 \le G < 2$, as shown in Fig. 5(c). This mode is similar to mode M_1; the only difference is that this mode can provide twice as much gain as the Mode-M_1. Moreover, the transients are under the limit of the rated output current, and the switch S_{sf} has no switching stress during transients. It can be stated that the buck FBI-HBR mode (Mode-M3) look smore attractive for implementation of the soft start as it provides wide gain range for pre-charging the converter capacitor without forming inrush currents.

B. Pre-charge with Boost Mode

In Mode-M_2 (Boost FBI-HBR Mode): This mode is used when $1 \le G < 1.5$. Fig. 5(b) shows the major waveforms of the system under test for $V_{LV} = 45$ V. The boost mode features a minimum gain, which forces the output capacitor to abruptly charge to the voltage that corresponds to it. After this hard pre-charging, the capacitor voltage can be smoothly regulated to

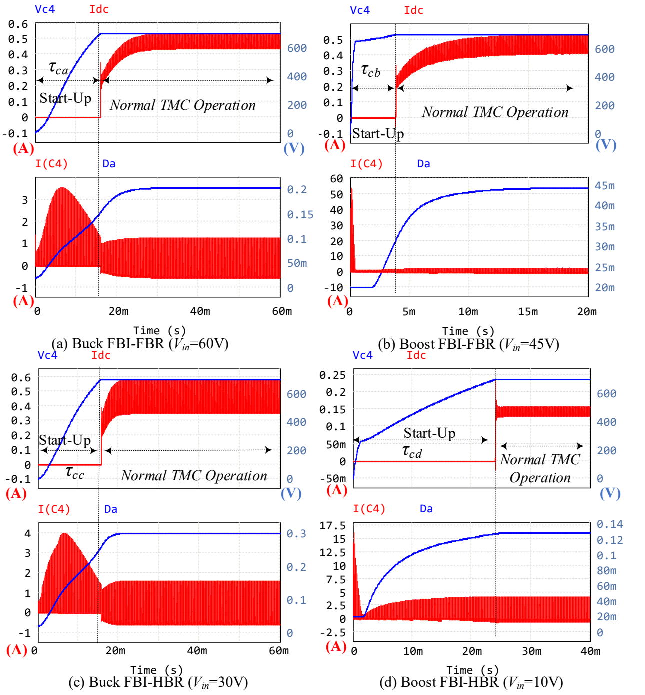


Fig. 5. Waveforms of pre-charging with various modes for input voltage (V_{LV}) range of 10 V to 60 V without ramped reference.

the reference dc bus voltage. Even though the dc bus current is under the safe limit of 0.5 A after the initial hard charging of the capacitor C_4, the converter cannot be considered as one having a soft start. The initial charging causes short-term current stress of the capacitor reaching 50 A, as evident from the inrush resonant current (I_{C4}) waveform in Fig. 5(b). Such current stress would cause a prohibitively high voltage swing on the resonant capacitor, which could result in its failure or overdesign. Similarly, Mode-M4 (boost FBI-HBR mode), which operates when $G \geq 2$, is similar to M2, but with twice higher gain. This mode has a high dc gain capability, which influences the initial charging of C_4. This mode is also highly stressful for the resonant circuit during initial transients, as shown in Fig. 5(d).

It could be summarized that boost modes are not suitable at the beginning of the soft start, but they can be used after an initial buck mode that cannot achieve the required voltage.

C. *Soft Start Strategy*

The soft start strategy can be implemented with open-loop or closed-loop control [15]. In open-loop control, the duty cycle is either fixed or ramped, depending on the modulation, to control the capacitor charging. In a closed loop, the duty cycle is controlled based on various feedback signals like input current (i_I), input voltage (V_{LV}), and capacitor voltage (V_{C4}) for gradual/smooth capacitor charging. At the same time, the topology morphing control has several modulation techniques with wider gain to charge the capacitor. Hence, mode M_3 (buck FBI-HBR) and mode M_4 (boost FBI-HBR) have been chosen to achieve the pre-charging for gain ranges of $0.5 \leq G < 2$ and $G \geq 2$, respectively.

A simple PI-based closed-loop control shown in Fig. 4 has been implemented for the pre-charging. It gradually increases the voltage on the capacitor C_4. For the gain $G \geq 2$, the converter is initialized in mode M_3 till the capacitor charges up to the gain limit and then shifts to M_4. This ensures that the boost mode is used from its minimum gain to limit the inrush

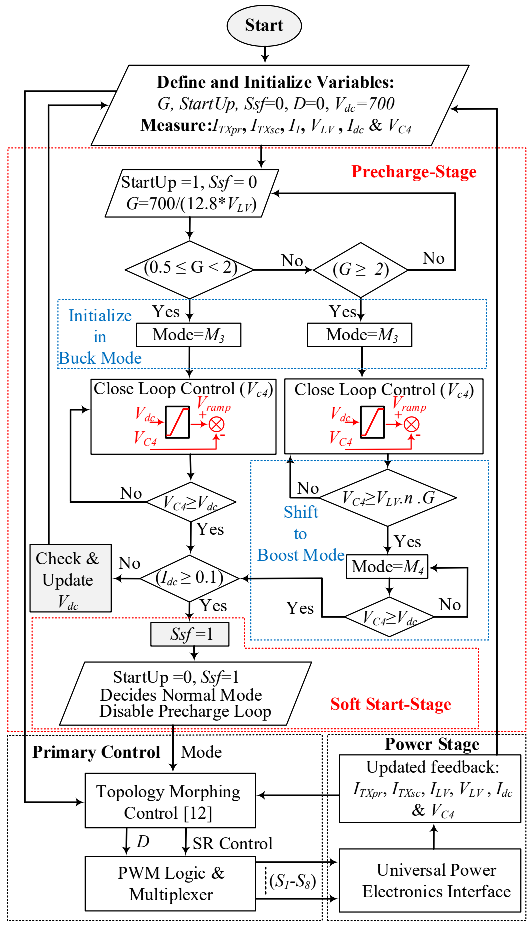


Fig. 6. Startup flowchart for topology morphing control of UPEI.

currents. After finishing pre-charging and the soft start stage, the converter control system shifts to normal TMC-based control and ends the soft start routine.

The startup flowchart with pre-charging of the capacitor C_4 is presented in Fig. 6. The startup algorithm initially verifies the operating constraints, like normalized dc voltage gain G, capacitor voltages V_{C4}, and input voltage V_{LV}. The pre-charging process starts from mode M_3, unless the input voltage is not within the allowed range. If the initial conditions require $G \geq 2$, mode M_4 will be engaged after the converter achieves its maximum gain in mode M_3 so the converter can pre-charge the capacitor C_4 to V_{dc}. After this, the switch S_{sf} can be turned on or off to establish the connection between the converter and the dc bus. The control system monitors the output current I_{dc}, which will flow through the body diode of the switch S_{sf} only after the capacitor C_4 is charged to the dc bus voltage. A designer can define a threshold for the diode current at which the safety switch S_{sf} is turned on.

D. *UPEI Control after Soft Start*

The topology configuration remains unchanged during soft start until it reaches the required input/output voltage ratio. After the soft start, the UPEI's control system initiates converter initialization. It starts from the input source type detection [11]. UPEI gradually increases the output current while assessing the input voltage behavior, i.e., the incremental conductance. The battery is a stiff voltage source, so it is easy to distinguish from the PV module. If a battery is detected at the input, the droop control is activated with a predefined characteristic. The global maximum power point tracking starts if a PV module is detected.

TABLE I. SYSTEM SPECIFICATIONS

Parameters	Label	Value
Input Voltage	V_{LV}	10-60 V
Output Voltage	V_{dc}	700 V
Output Power	P_o	350 W
Components		
Input/Output Capacitor	C_1/C_4	150/5 µF
Output Capacitor ESR	R_{C4}	33 mΩ
Blocking/Series-Resonant Capacitance	C_2/C_3	52µF /25 nF
Transformer Turn Ratios	n	12.8
Resonant Inductance	L_r	95 µH
Magnetising Inductance	L_m	1.95 mH
Cable Inductance	X_{bus}	10 µH
Cable Resistance	R_{bus}	100 mΩ

The comprehensive control of the converter has been presented in [11]. Next, the system under study has been simulated to verify the effectiveness of the proposed soft start strategy for the given converter.

IV. Results and Discussion

The specifications related to the system under study have been listed in Table I. For practicality, a cable impedance ($Z_{bus} = R_{bus} + i{\cdot}X_{bus}$) has also been considered between the converter and dc bus. The converter parameters have been designed for a rated output power of 350 W and operation in a 700 V dc microgrid.

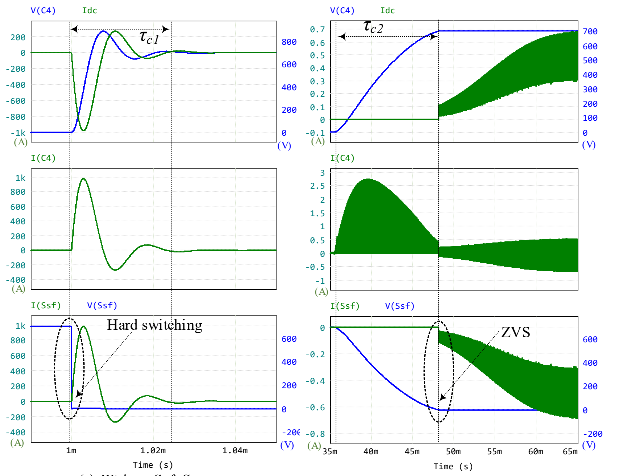
A. System Start without Pre-charging

Fig. 7(a) represents the converter operation when the safety switch is turned on without pre-charging of the output capacitor. A massive inrush current can be observed flowing from the dc bus to the converter. This inrush current is high enough to trigger the solid-state protection devices commonly used in dc microgrids. This can also lead to component failures due to short-term overvoltage or overheating.

B. System Soft Start with Pre-charging

As discussed in Section II, the TMC-based closed-loop control has been implemented to suppress the inrush currents in the converter resonant tank and dc bus. Ramped dc voltage serves as the reference and capacitor voltage is the feedback signal to control its pre-charging. Since the input voltage can vary from 10 V to 60 V, the buck FBI-HBR mode is selected to initialize the charging process over others based on its high gain regulation property, as each is restricted by its voltage gain limit. The ramped reference voltage ensures the smooth charging of the capacitor irrespective of the mode of operation. As shown in Fig. 7(b), τ_{c2} is the charging time of the capacitor that can be controlled with both an overdamped controller or a ramped reference voltage or both depends on designer. Alternatively, dual loop control with an inner current control loop that limits the reference input current can also control the smooth charging of the capacitor.

Fig. 5(a) and Fig. 8(b) demonstrate the converter operation under the same mode and converter gain, but here the charging times differ due to the different feedback signals used for charging the capacitor. In Fig. 5, the input current was considered as feedback to control the charging, while Fig. 8 is the result of choosing the ramped voltage as reference. Since the output voltage of the converter is directly related to the control (duty) of the converter. Hence, considering the ramped voltage as the reference can simply control the rate of charging of the capacitor, which can be observed from the waveforms of V_{c4} and V_{ramp} in Fig. 8(a) and Fig. 8(b).



(a) *Without Soft Start-up* (b) *With Soft Start-up*

Fig. 7. Simulated connection of a UPEI to a dc bus with and without pre-charging of the capacitor C_4.

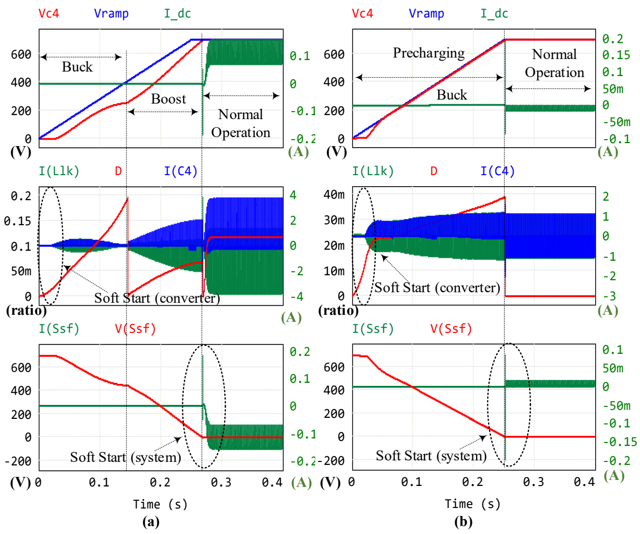


Fig. 8. Soft start strategy simulations at (a) $V_{LV} = 10$ V and (b) $V_{LV} = 60$ V.

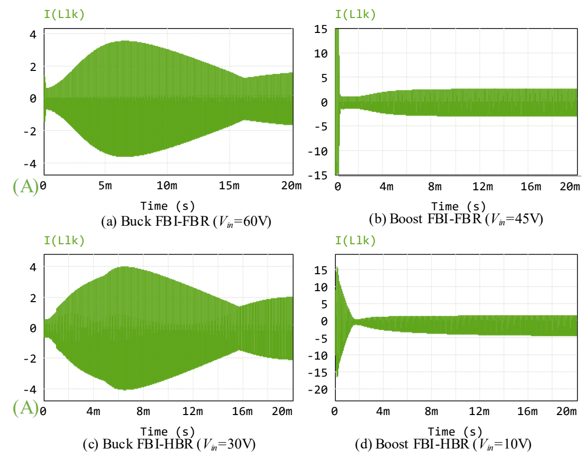


Fig. 9. Resonant tank current during startup and normal operation at 700 V output voltage for all four operating modes.

Additionally, pre-charging with each operating mode with possible topology configurations has been analyzed to showcase the feasibility of a soft start in each mode. As a key objective of this work, the overall soft start can be achieved when the startup of the converter and connection of the dc bus are established smoothly without inrush to the resonant tank and dc bus current, respectively, along with the smooth charging of the output capacitor.

Hence, the soft start strategy given in Fig. 6 is applied to the test, which states that the converter will start operation in buck FBI-HBR mode to cover the maximum gain range. Fig. 8(a) represents the soft start operation in which the converter starts in buck mode with V_{in}= 60 V. This operation ensures the smooth pre-charging and soft start of both the converter and system. Similarly, Fig. 8(b) represents the boundary condition operation when only 10V input is available to charge the capacitor. Hence as per the startup strategy, the capacitor will get charged smoothly with fixed buck mode upto its maximum possible gain, which results in charging the capacitor with minimum possible gain of the boost mode. The pre-charging of the capacitor up to normalized gain will make boost mode operation smooth and prevent the possibility of inrush current in the converter. The startup or transient condition might affect the operation of the converter as Fig. 9(a) to Fig. 9(d) shows the converter's performance during startup. This reveals that the resonant current's starting peak is under the rated limit only in buck mode operations, confirming the optimal selection of modes during soft start.

V. Conclusion

This work presents the idea for soft start of the overall system and pre-charging of DC link capacitors of the series-resonant converter based UPEI. This suppresses the inrush currents at both the converter and the DC bus and prevents false trip-down of the 700 V DC microgrid and its protection devices. This also eliminates the pre-charging circuitry and uses a single safety switch to connect the converter to the DC bus. A simple strategy has been implemented using gain-dependent TMC operation to charge the capacitor initially. This limits the charging currents from the DC link and the converter end, maintaining the integrity of system specifications. The PSIM was used to simulate the work and validate the startup strategy to support the pre-charge or the gradual charging of the output capacitor. The considered charging time is 250ms but it is controllable and can be increased if required. Moreover, the soft turned-on for a single safety switch has been achieved, ensuring minimum inrush current (within the limit of the output rated current), and extended switch reliability. Furthermore, the capacitor charging can be controlled with a dual loop, keeping input current as inner loop feedback, for soft start in intermittent source applications like PV.

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References

[1] G. A. Mudiyanselage, N. Keshmiri, and A. Emadi, "A Review of DC-DC Resonant Converter Topologies and Control Techniques for Electric Vehicle Applications," *IEEE Open Journal of Power Electronics,* vol. 4, pp. 945-964, 2023.

[2] M. Khatua et al., "High-Performance Megahertz-Frequency Resonant DC–DC Converter for Automotive LED Driver Applications," *IEEE Trans. Power Electron.*, vol. 35, no. 10, pp. 10396-10412, Oct. 2020.

[3] A.H. Okilly, N. Kim, J. Baek, "Inrush Current Control of High Power Density DC–DC Converter," *Energies*, 13, no. 17: 4301, 2020.

[4] T. Jalakas, A. Chub, I. Roasto and D. Vinnikov, "Hybrid Residual Current Device and Solid State Circuit Breaker for Residential DC Microgrids," 2024 19th Biennial Baltic Electronics Conference (BEC), Tallinn, Estonia, 2024, pp. 1-5.

[5] Y. Wei, Q. Luo, and A. Mantooth, "Overview of Modulation Strategies for LLC Resonant Converter," *IEEE Trans. Power Electron.,* vol. 35, no. 10, pp. 10423-10443, Oct. 2020.

[6] M. Yang, K. Jin, X. Ruan and M. Xu, "Soft Start Strategy for Bi-directional DC-DC Converter," 2007 *IEEE Power Electron. Specs. Conf.*, USA, 2007, pp. 161-164.

[7] S. Kim, J. Kucka, G. Ulissi, S. -N. Kim and D. Dujic, "Solid-State Technologies for Flexible and Efficient Marine DC Microgrids," in IEEE Transactions on Smart Grid, vol. 12, no. 4, pp. 2860-2868, July 2021.

[8] M. Forouzesh, Y. P. Siwakoti, S. A. Gorji, F. Blaabjerg, and B. Lehman, "Step-Up DC–DC Converters: A Comprehensive Review of Voltage-Boosting Techniques, Topologies, and Applications," *IEEE Trans. Power Electron.*, vol. 32, no. 12, pp. 9143-9178, Dec. 2017.

[9] R. Ramabhadran, X. She, Y. Levy, J. Glaser, R. Raju and R. Datta, "Universal AC input high density power adapter design with a Clamped Series Resonant Converter," 2015 IEEE Energy Conversion Congress and Exposition (ECCE), Montreal, QC, Canada, 2015, pp. 5857-5864.

[10] I. Cohen, "Series resonant circuit with inherent short circuit protection," United States Patent US6225862B1, 2001.

[11] V. Sidorov, A. Chub, D. Vinnikov and A. Lindvest, "Novel Universal Power Electronic Interface for Integration of PV Modules and Battery Energy Storages in Residential DC Microgrids," in IEEE Access, vol. 11, pp. 30845-30858, 2023.

[12] V. Sidorov, A. Chub and D. Vinnikov, "Bidirectional Isolated Hexamode DC–DC Converter," *IEEE Trans. Power Electron.*, vol. 37, no. 10, pp. 12264-12278, Oct. 2022.

[13] V. Sidorov, A. Chub and D. Vinnikov, "Feasibility Study of Universal Power Electronics Interface Operation in 350 V and 700 V Residential DC Microgrids," in *Proc. IEEE 17th Int. Conf. Comp. Power Electron. Power Eng.,* 2023, pp. 1-7.

[14] T. Langbauer, A. Connaughton, F. Vollmaier and K. Krischan, "Pre-Charging of a DC-Link Capacitor from a High Voltage Battery," in *Proc.* 2020 *IEEE 21st Works. Cont. and Model. Power Electron.*, Denmark, 2020, pp. 1-6.

[15] T. Gao, Y. Wang, Y. Gao, G. Sun, H. Wang and J. Hou, "Hybrid Control-Based Closed-Loop Soft Startup Method for LLC Resonant Converters," *Electronics*, 2023, 12, 4563.

[16] N. -G. Kim, S. -W. Jo, B. Han, H. -H. Choi and M. Kim, "Highly Efficient Bidirectional Current-Fed Resonant Converter Over a Wide Voltage Gain Range," *IEEE Trans. Indus. Electron.*, vol. 68, no. 11, pp. 10913-10927, Nov. 2021.

[17] S. Chauhan, A. Blinov, A. Chub, and D. Vinnikov, "Active Clamped Dual Current-Fed Bidirectional DC-DC Converter for Wide Voltage Range Applications," in *Proc. IEEE 65th Int. Sci. Conf. Power Elect. Eng. Riga Tech. Uni.,* 2024, pp. 1-7.

[18] A. Chub, D. Vinnikov and J. -S. Lai, "Input Voltage Range Extension Methods in the Series-Resonant DC-DC Converters," 2019 *IEEE 15th Brazilian Power Electronics Conference and 5th IEEE Southern Power Electronics Conference (COBEP/SPEC)*, Santos, Brazil, 2019, pp. 1-6.