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Boost Derived Switched Boost Inverter for Simultaneous DC & AC Applications

Jince Jose[1], M V Aleyas[2], Kavitha Issac[3]

P.G. student, Mar Athanasius College of Engineering, Kothamangalam, Kerala, India [1]

Professor, Mar Athanasius College of Engineering, Kothamangalam, Kerala, India[2]

Assistant Professor, Mar Athanasius College of Engineering, Kothamangalam, Kerala, India[3]

ABSTRACT: The Z-source inverter (ZSI) employs an *LC* impedance network between thepower source andinverterbridge. The unique feature of the ZSI is that it can operateeither in buck or boost mode with a wide range of obtainableoutput voltages from a given input voltage. The Z-source inverter alsoexhibits better electromagnetic-interference noise immunity whencompared to a traditional voltage-source inverter (VSI). Switched boost inverter (SBI) which is derived from Z source inverter exhibits similar advantages of ZSI with lower number of passive components and more number of active components. By utilizing the shoot through capability of switched boost inverter we can use SBI as a substitute for single switch in the boost converter. Thus SBI provide the AC output power and boost converter provide the DC output power. DC output voltage can be varied from 280V to 160V and AC output voltage can be varied from 140V to 85V with input DC source of 100V.The value of D can be varied from 0 to 0.5. The steady-state analysis of SBI, along with its pulse width modulation(PWM) control strategies, have been discussed. Simulink model is used to validate the operation of the converter.

KEYWORDS:Pulsewidth modulation (PWM), Z source inverter (ZSI), Switched boost inverter (SBI)

I. INTRODUCTION

Nanogrid architectures are being increasingly incorporated in modern smart residential electrical power systems. These systems involve different load types- DC as well as AC, efficiently interfaced with different kinds of energy sources (conventional or non-conventional) using power electronic converters. Fig. 1 shows the schematic of a system, where a single DC source (V_{dcin}) (e.g., Solar Panel, Battery, Fuel Cell, etc.) supplies both DC (V_{dcout}) as well as AC loads (V_{acout}). The architecture of Fig. 1(a) uses separate power converters for each conversion type (DC-DC and DC-AC) while Fig. 1(b) utilizes a single power converter stage to perform both the conversions. The latter converter, referred to as a Hybrid converter in this paper, has higher power processing density and improved reliability (resulting from the inherent shoot-through protection capability). These qualities make them suitable for use in compact systems with both DC as well as AC loads. For example, an application of a hybrid converter can be to power an AC fan and a LED lamp both at the same time from a solitary DC input in a single stage.

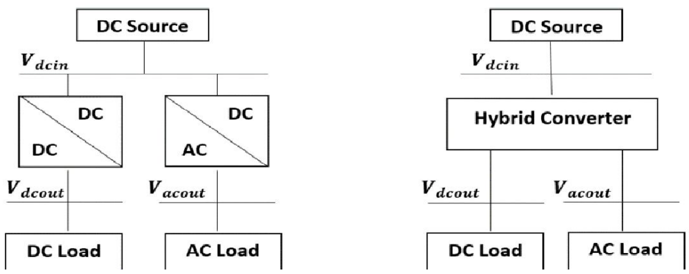

Fig. 1 Architectures supplying DC and AC load from a single DC source. (a) Dedicated power converter based architecture and (b) Hybrid converter based architecture.

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The Z source inverter (ZSI) consists of an X-shaped passive network to couple the main power converter andthe power source. Unlike a traditional voltage-source inverter (VSI), the ZSI has the advantage of either stepping up or stepping down the input voltage by properly utilizing the shoot-through state of the inverter bridge [2]. As a result, the output voltage of the converter can be either higher or lower than the input voltage as per the requirement. Inaddition, the ZSI also possesses robust electromagnetic interference(EMI) noise immunity, which is achieved by allowing theshoot-through of the inverter leg switches. These features makethe ZSI suitable for various applications such as renewablepower systems, adjustable speed drive systems, uninterruptiblepower supplies[3]-[5]etc. This paper presents a novel power converter called switched boost inverter (SBI) which works similarly to a ZSI. This converter uses more active components and lower number of inductors and capacitors compared to the original ZSI while retaining its operational advantages. Also this paper presents a new converter topology for getting simultaneous AC and DC output derived from both boost converter and switched boost inverter.

II. SWITCHED BOOST INVERTER (SBI) TOPOLOGY

The schematic of the SBI, shown in Fig. 2, in which a switched boost network comprising of one active switch (S), two diodes (D_a,D_b), one inductor (L), and one capacitor (C) is connected between voltage source V_g and the inverter bridge. A low-pass LC filter is used at the output of the inverter bridge to filter the switching frequency components in the inverter output voltagev_{AB}.

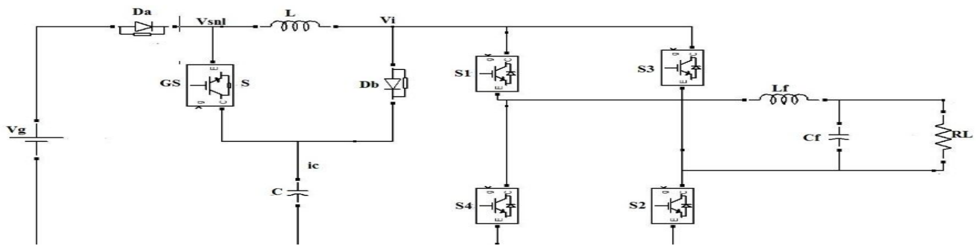

Fig.2Circuit diagram of SBI topology.

Similar to a ZSI, the SBI also utilizes the shoot-through state of the H-bridge inverter (both switches in one leg of the Inverter are turned on simultaneously) to boost the input voltage $V_g$to capacitor voltage V_C.To explain the steady-state operation of the SBI, assume that the inverter is in shoot-through zero state for duration D.$T_S$in a switching cycle T_S. The switch S is also turned on during this interval. As shown in the equivalent circuit of Fig. 3(a),the inverter bridge is represented by a short circuit during this interval. The diodes D_a and D_b are reverse biased (as $V_C > V_g$), and the capacitor C charges the inductor L through switch S and the inverter bridge. The inductor current in this interval equals the capacitor discharging current. For the remaining duration in the switching cycle $(1 - \mathrm{D}).T_S$, the inverter is in non-shoot-through state, and the switch S is turned off. The inverter bridge is represented by a current source in this interval as shown in the equivalent circuit of Fig. 3(b). Now, the voltage source V_g and inductor L together supply power to the inverter and the capacitor through diodes D_a andD_b. The inductor current in this interval equals the capacitor charging current added to the inverter input current. Note that the inductor current is assumed to be sufficient enough for the continuous conduction of diodes D_a and D_b for the entire interval $(1 - \mathrm{D}).T_S$.

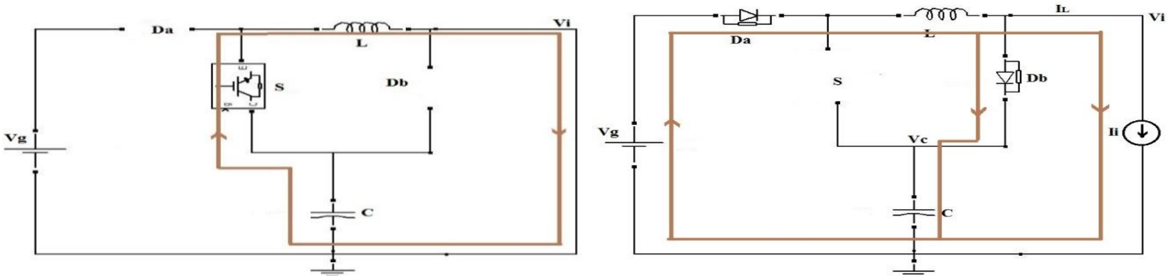

Fig. 3 (a) Equivalent circuit of SBI during $D.T_S$interval, (b) equivalent circuit of SBI during $(1 - D).T_S$interval

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Fig. 4 shows the steady-state waveforms of the converter operation for one switching cycle T_S with respect to the gate signal G_S of switch S. From Fig. 3(a) and (b), one has

$$v_L(t) = \begin{cases} v_C(t), & \text{if } 0 < t < D.T_s \\ V_g - v_C(t), & \text{if } D.T_s < t < T_s \end{cases} \quad (1)$$

$$i_C(t) = \begin{cases} -i_L(t), & \text{if } 0 < t < D.T_s \\ i_L(t) - i_i(t), & \text{if } D.T_s < t < T_s \end{cases} \quad (2)$$

$$v_i(t) = \begin{cases} 0, & \text{If } 0 < t < D.T_s \\ v_C(t), & \text{if } D.T_s < t < T_s \end{cases} \quad (3)$$

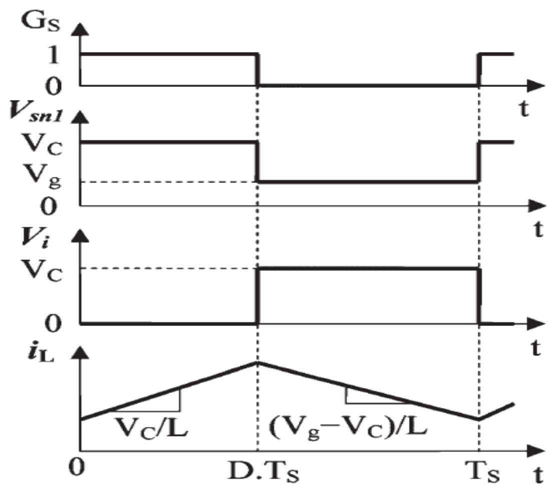

Fig. 4.Steady-state waveforms of SBI.

Here, V_C and I_L are dc components in $V_C(t)$ and $I_L(t)$, respectively, and I_i is the current drawn by the inverter bridge in the $(1-D).T_S$ Interval. Under steady-state, the average voltage across the inductor and the average current through the capacitor in one switching cycle should be zero. Using volt–second balance, we have

$$V_C.D + (V_g - V_c).(1-D) = 0 \rightarrow \frac{V_C}{V_g} = \frac{1-D}{1-2D} \quad (4)$$

Similarly,

$$-I_L.D + (I_L - I_i).(1-D) = 0 \rightarrow \frac{I_L}{I_i} = \frac{1-D}{1-2D} \quad (5)$$

The average dc link voltage V_i can be calculated as

$$V_i = 0.D + V_C.(1-2D) = V_C. \quad (6)$$

From equations (4)–(6), it can be observed that the expressions for the conversion ratios (V_C/V_g) and (I_L/I_i) of SBI are the same as those for a ZSI, while the average dc link voltage of SBI is $(1-D)$ times that of ZSI.The switching states of SBI and ZSI are the same provided thatthe LC impedance network of ZSI is symmetrical.

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III. PWM CONTROL OF SBI

In this paper, a modified PWM control strategy for the SBIis developed based on the traditional sine-triangle PWM withunipolar voltage switching [9]. In this scheme, the switch S willhave only two switching cycles perT_S. Also, the switchingfrequency of S is always constant. Fig. 5 shows the schematic of the control circuit to generate the PWM control signal for the converter using the modified PWM control scheme, the gate controlsignals for switches S_1 and S_2 are generated by comparingthe sinusoidal modulation signals $v_m(t)$ and $-v_m(t)$ with a high frequency triangular carrier $v_{tri}(t)$ ofamplitude V_P. The frequency (f_S) of the carrier signal is chosensuch that $f_S - f_0$ Therefore, $v_m(t)$is assumed to be nearlyconstant during a switching cycle. The signals$ST_1$and ST_2 are generated by comparing $v_{tri}(t)$ with twoconstant voltages V_{ST} and $-V_{ST}$, respectively. The purpose ofthese two signals is to insert the required shoot-through interval$D.T_S$In the gate control signals of the inverter bridge. Now, thegate control signals for switches S_1,S_4 and S can be obtainedusing the logical expressions given as follows:

$$G_{S3} = \overline{G_{s2} \wedge ST_1}\ ,\ G_{S4} = \overline{G_{s1} \wedge ST_2},\quad G_S = \overline{ST_1 \wedge ST_2} \tag{7}$$

The resulting voltage waveforms at the input (V_i) and output (v_{AB}) terminals of the inverter bridge. It can be observed that v_{AB} has nine intervals in each switching cycleT_S.

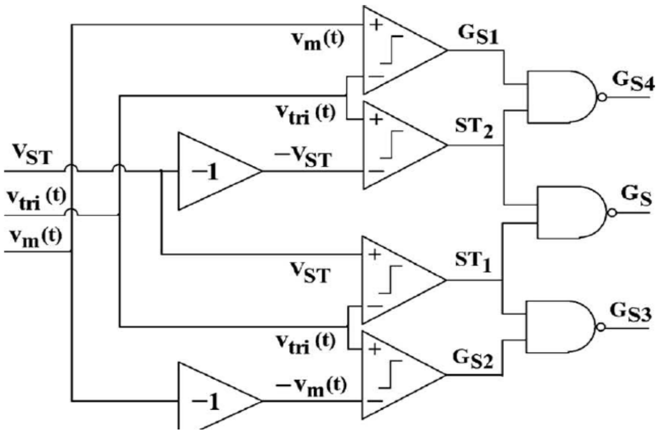

Fig. 5 Schematic of the PWM control circuit,

a. Mathematical Relation Between V_{ST} and Shoot-Through Duty Ratio D

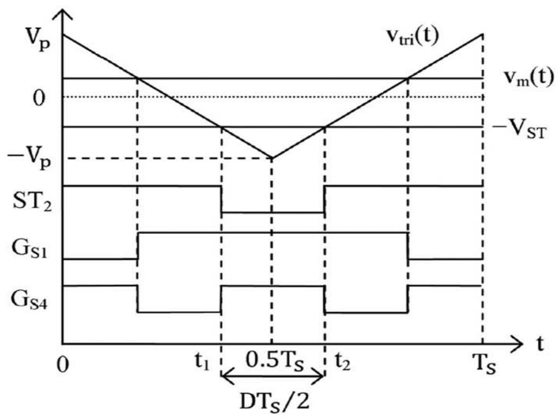

Fig.6Generating shoot-through in leg A of Inverter Bridge.

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$$v_{tri}(t) = \begin{cases} \frac{V_p}{T_s/4}\left(t - \frac{T_s}{4}\right) & \text{if } 0 < t < \frac{T_s}{2} \\ \frac{-V_p}{T_s/4}\left(t - \frac{3\,T_s}{4}\right) & \text{if } \frac{T_s}{2} < t < T_s \end{cases} \quad (8)$$

$$v_{tri}(t_1) = v_{tri}(t_2) = -V_{ST} \text{ And } t_2 - t_1 = \frac{DT_s}{2} \quad (9)$$

Now, using equations (8) and (9), the expressions for t_1 and t_2 can be obtained as

$$t_1 = \frac{T_s}{4}\left(1 + \frac{V_{ST}}{V_p}\right), \; t_2 = \frac{T_s}{4}\left(3 - \frac{V_{ST}}{V_p}\right) \quad (10)$$

Substituting t_1 and $t_2$in equation (9), the following can be obtained:

$$D = 1 - \frac{V_{ST}}{V_p} \quad (11)$$

IV. SIMULINK MODEL OF PWM GENERATION CIRCUIT

Fig. 5 shows the Simulink model for the modified unipolar PWM control strategy. The signals shown in Fig.8 provided to gates of the controllable switches S_1-S_2 *and* S. V_{ST}A DC signal controls the duration of shoot-through interval, hence adjust the duty cycle for the boost operation. $V_m(t)$ Controls the modulation index for inverter operation. Fig. 11 and 12 shows the DC and AC output voltage waveform. DC voltage gain can be achieved by boost derived switched boost inverter is equivalent to boost converter, and is around four.

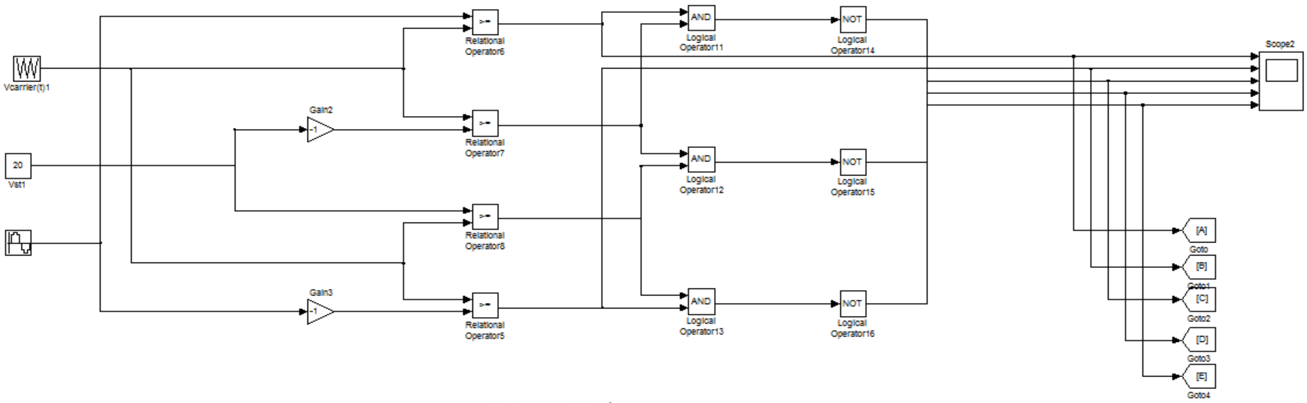

Fig.7Simulink Model of PWM Generation Circuit

V. SIMULINK MODEL OF BOOST DERIVED SWITCHED BOOST INVERTER

The boost derived switched boostinverter is derived from the switched boost inverter and boost converter. By replacingsingle switch in the boost converter by switched boost inverter we can derive boostderived switched boost inverter (BDSBI). Since SBI utilizes shoot through state inthe working, this state can be utilized for the working of boost converter. By varyingthe duty ratio of PWM control, the output AC and DC voltage can be adjusted.Same control scheme used for SBI can be used for BDSBI.For simulation of the proposed hybrid converter Parameters of the different circuit components are taken as: Input inductor (L) =5mH, DC capacitor (C) =1 mH, AC filter inductor

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L_{ac}=4.6μH, AC filter capacitor (C_{ac}) =50μF, DC load R_{dc}=20Ω, AC load R_{ac}=25 Ω and Switching frequency is taken as 10 KHz [1].

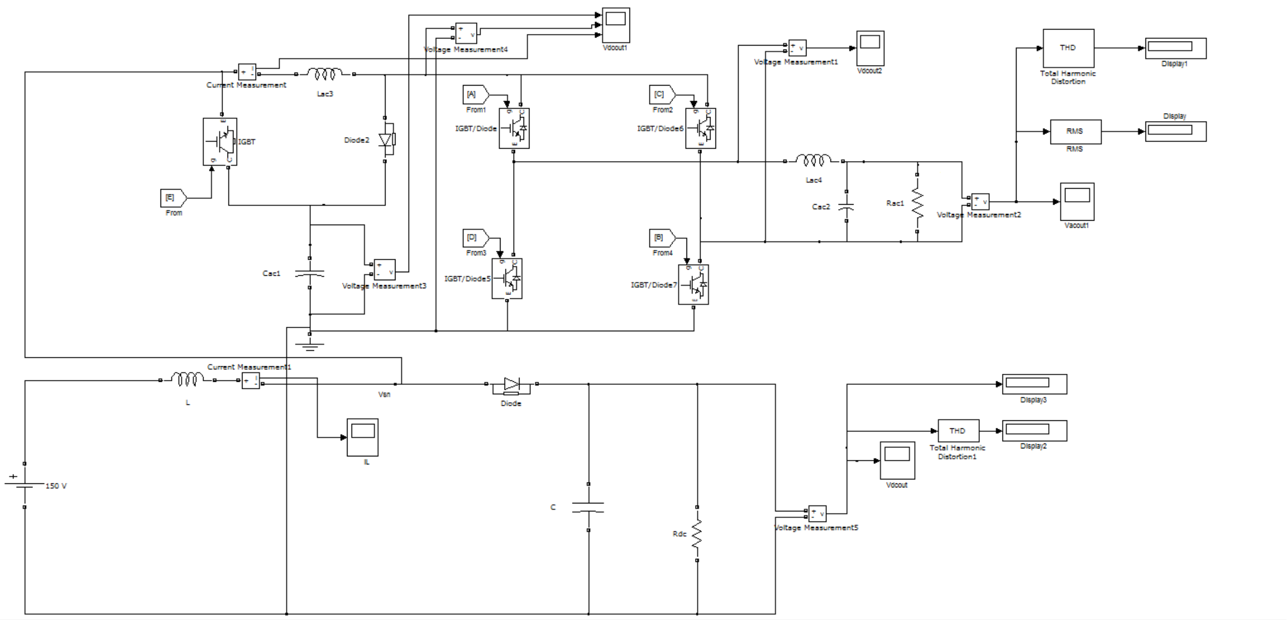

Fig.8Simulink Model of Boost Derived Switched Boost Inverter

VI. SIMULATION RESULTS

A Simulink model of the SBI, along with the PWM control circuit of Fig.8 andFig.9, is designed and used to verify the proposed PWM technique and theoretical analysis given in the previous sections. Section V gives the parameters used for simulation ofthe SBI. For BDSBI, the output DC voltage can be varied from 281V(THD=0.7314) to 162V (THD=0.4314) and AC voltage from 140V (THD=0.01163)to 85V (THD=0.0584) from an input voltage of 100V for a variation of duty ratio(D) from 0.47 to 0. The duty ratio cannot be increased above 0.5. Table 4.1 showsthe DC and AC output voltages for different values of D.

TABLE I
DC and AC output for different values ofD

D	DC Voltage	AC Voltage
0.47	281	140
0.40	240	128
0.30	209	118
0.20	162.7	96
0.10	162	85

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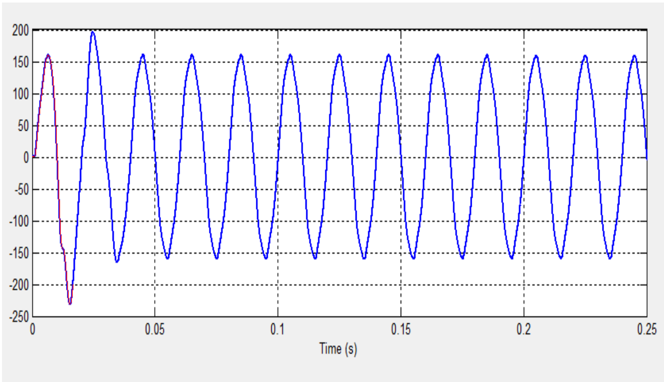

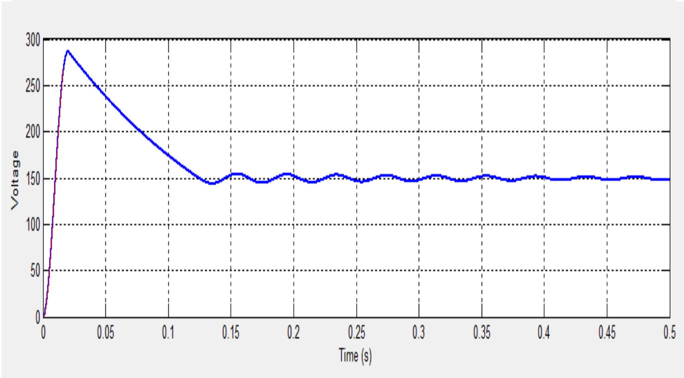

Fig. 11 Output AC voltage waveformFig. 12Output DC voltage waveform

VI.CONCLUSION

This paper proposes a new converter topology called boost derived switched boost inverter which can supply simultaneously both AC and DC load from a single DC source. Switched boost inverter which is derived from Z source inverter having better electromagnetic-interference, noise immunity when compared to a traditional voltage-source inverter (VSI) inherits all the properties of ZSI.The proposed boost derived switched boost inverter has the following advantages, shoot-through condition does not cause any problem on working of the circuit hence improves the reliability of the system, Implementation of dead time circuitry is not needed, Independent control over AC and DC output and the converter can also be adapted to generate AC outputs at frequencies other than line frequencies by a suitable choice of the reference carrier waveform. The output DC voltage can be varied from 281V to 162V and AC voltage from 140V to 85V for a variation of duty ratio (D) from 0.5 to 0.

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