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A NOVEL SWITCHING SCHEME FOR SINGLE PHASE VS INVERTER USING VALUE OF OUTPUT CURRENT AS MODULATING SIGNAL

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Abstract— **Power electronic devices and especially inverters have emerged as one of the most important devices of power electronics based system. With the time inverters (both 1–phase 3–phase) are gaining more attention due to their application in renewable energy system and smart grid system. These inverters and other power electronics devices are basically combination of power electronic switches, which are operated and controlled by some switching scheme. This paper is presenting a new switching scheme for single phase H-bridge VS (voltage Source) DC–AC inverter. The new Switching Scheme for Single Phase VS Inverter using value of output current as modulating signal has been designed and presented in this paper. The simulation has been carried out under different loading conditions and results have been compared with the results of PWM under same loading conditions. The new switching scheme shows several advantages over the PWM scheme.**

Keywords— PWM, DC – AC inverter, Feedback, Switching

I. Introduction

Inverters are most important device of power electronics family. Now-a-days DC–AC inverters have got vital industrial application ranging from small ac motor drives, communication system, power supplies to renewable energy system. The inverter is basically combination of power electronics switches and these switches operate in ON–OFF mode. By operating the switches in proper sequence a DC input can be converted in to AC output. This sequence of operation of the switches is termed as switching scheme or switching strategy. As switching scheme controls the operation of inverter and thus the output, harmonics in output current and voltage, quality of power and efficiency are also controlled by switching scheme. Hence an efficient switching scheme for inverter is need of time.

During the process of designing a new switching scheme, there are few important factors that must be considered. These factors are listed below.

1) Switching losses
2) Total harmonic distortion (THD)
3) Output RMS voltage and current
4) Output peak voltage and current
5) Practical implementation
6) Wide range of operation
7) Economic factors

Various literatures show that during last decade, several approaches have been applied to develop an efficient switching scheme and implement them. Few major names in this category are square pulse switching [1], PWM (pulse width modulation) [1] [2], RPWM (random PWM), SHE (selected harmonic elimination) [1] [3], hysteresis modulation [4]-[6] etc.

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In this paper a new switching scheme has been presented for single phase H-bridge VS DC–AC inverter. Also the simulations have been performed under various loading conditions to analyze its performance. This new switching scheme uses the concept of feedback and some concept of hysteresis modulation scheme. The simulation results of new switching scheme are compared to the simulation results of PWM switching scheme under similar loading conditions. This paper has been organized in five sections. Section II discusses the concept of modified switching scheme. Section III presents the implementation method for the switching scheme. The simulation and outcome of the new switching scheme is discussed and compared with PWM scheme in section IV. Section V discusses conclusion.

II. MODIFIED SWITCHING SCHEME

The modified switching scheme has been developed for single phase H-bridge VS DC–AC inverter. A circuit model of single phase H-bridge VS DC–AC inverter is shown in fig.1, which has been used throughout the process of development and testing of new switching scheme. The inverter model in fig.1 has four IGBT switches S1, S2, S3, and S4. These IGBT switches are controlled via gate pulses provided through G1, G2, G3 and G4 respectively. Switching scheme is basically logic for the proper sequence which is implemented through a programmable logic circuitry. The new switching scheme is discussed below.

A. *New switching scheme*

The block diagram of new switching scheme is shown in fig.2. In new switching scheme the readings of output current in ammeter is taken as feedback. Thus the feedback signal is a copy of load current. This feedback signal can be named as signal B. The reference signal for the feedback switching scheme is a sinusoidal signal define as in (1).

$$A = A_{max}\sin(\omega t) \qquad (1)$$

where A_{max} is the maximum value of reference signal A. The reference signal in this switching scheme is actually a copy of desired sinusoidal load current. During the process of generating the gate pulses, the switching circuit compares feedback signal B with respect to the sinusoidal reference signal A. Fig.3 (a) shows a conceptual diagram the of new switching scheme for positive cycle. When the feedback signal B is less than the reference signal A, the switching circuit generates ON pulse to the switch S1 and S2. This ON pulse brings the switches S1 and S2 in conducting mode and as soon as switches S1 and S2 comes in conducting mode the load current and thus the feedback signal starts increasing. When the load current and thus the feedback signal B attains higher value than the reference signal A, the switching circuit generates OFF pulse for switches S1 and S2. This OFF pulse blocks the conduction mode of switches S1 and S2. This decreases the value of load current (and feedback signal) to the level of reference or even lower than that. A similar process is being followed for the negative pulse also. Switches S1 and S2 operate during positive cycle and switches S3 and S4 operates during negative cycle of output current. A plot showing actual feedback, reference and gate signals are shown in fig.3 (b).

B. *Reference signal*

The reference signal plays an important role in any switching scheme. The complete process of switching (or pulse modulation) depends on the selected reference signal. As discussed earlier, the reference signal for new switching scheme is a sinusoidal signal defined in (1). This reference signal is basically a copy of desired load current and the load current depends on load, so, may not have same value for all kind of load. So, the reference signal also may not be same for all kind of application.

The value of amplitude of desired load current and thus reference signal will vary from load to load. Considering the above facts the value of A_{max} has been kept variable and thus the reference signal has been defined in two parts.

1) Initial reference signal
2) Updated reference signal.

Initial reference signal is defined with a small constant value of amplitude as in (2). Here a_{max} is constant value and is less than A_{max}.

$$A = a_{max}\sin(\omega t) \qquad (2)$$

This initial reference signal is required to initiate the switching process. As soon as the switching

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process begins and inverter starts delivering power to the load, the reference signal must be updated according to the load demand again and again until its amplitude reaches to maximum value A_{max} as shown in fig.4.

C. *Problems and modification*

The defined switching scheme has a problem also. Fig.3 (b) shows that in the second half of positive cycle when the gate pulse is OFF even though the feedback signal (load current) of the inverter is not following the reference signal. Load current is higher than the reference current during this period and just switching off the switches S1 and S2 is not sufficient enough to decrease the value of feedback signal (load current) to the level of reference signal. This problem arises because of inductive nature of the load. The inductive property of load causes the storage of energy during the first half of positive cycle when the load current is increasing and during second half of the cycle it behaves as a current source and causes the excess value of load current.

The solution of this problem has been driven from the concept of hysteresis control (or modulation) scheme for inverters [4]-[6]. Similar to the tolerance band of hysteresis modulation the concept of error band has been introduced to tackle the above problem. By recording the difference between reference signal and feedback signal one can obtain the error signal. If we observe the error signal shown in fig.5 then we can analyze that the error between the reference signal and feedback signal is almost in a fixed limit except the specific period of second half of positive or negative cycle. This is the period during which the inductive effect of load is causing trouble.

As the error signal is almost in fixed limit except the specific period, we can define an error band as a band of fixed limit for the error signal. Furthermore two new terminologies have been introduced.

a) Positive error

Positive error is the error between reference signal and feedback signal during positive cycle.

b) Negative error

Similar to positive error, negative error is the error between reference signal and feedback signal during negative cycle.

Using the above concept of error band and positive and negative error, an additional switching scheme has been defined. Switching circuit compares the error with the error band and accordingly generates gate pulses. During the positive cycle when the positive error becomes more than the error band the switching circuit generates ON pulse for switches S3 and S4. This establishes a negative voltage across the load with respect to existing voltage and tries to establish a current in opposite direction and so the excess energy gets balanced. A similar logic is applied to the negative cycle also. Switches S3 and S4 get operated during positive cycle and S1 and S2 during negative cycle.

Now this error band based switching scheme is applied to the inverter along with the previously defined new switching scheme. This hybrid scheme is named as modified switching scheme.

III. IMPLEMENTATION

Developed switching scheme is implemented using the S-function block of SIMULINK facility of MATLAB R 2011b. A program has been written to realize the modified switching scheme. Simulation and testing for the modified switching scheme is performed on the model of single phase VS DC–AC inverter shown in fig.1. The flowchart of the complete switching scheme is shown in fig.6.

The power electronic switches of inverter are controlled by gate pulses. The output of the switching circuit is applied to the gate terminal of these switches. The gate terminals are named as G1, G2, G3 and G4 for switches S1, S2, S3 and S4 respectively. Logic ‘1’ on gate terminal of any switch represent ON pulse for respective switch and similarly logic ‘0’ represents the OFF pulse. The error band is represented by E_b in the description and flowchart below. The step by step description of the modified switching scheme is as follows.

Step 1) Initialize the switching circuit.

Step 2) Define the basic parameter such as frequency (f_m) time period (T_m), sampling time (T_s) and set time t=0;

Step 3) Define initial reference current as in (2) $A = a_{max}\sin(\omega t)$

Step 4) Evaluate positive (+ve) error and negative

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(-ve) error.

$+ve\ error = A - B$ (During +ve cycle) (3)

$-ve\ error = B - A$ (During –ve cycle) (4)

Step 5) If $t \geq \frac{T_m}{2}$; then go to step 6. Otherwise go to step 9.

Step 6) If $A > B$; then G1 = G2 = 1 and G3 = G4 = 0. Otherwise go to step 7.

Step 7) If $+ve\ error > E_b$; then G1 = G2= 0 and G3 = G4 =1. Otherwise G1 = G2 = G3 = G4 = 0.

Step 8) Go to step 11.

Step 9) If $B > A$; then G1 = G2 = 0 and G3 = G4 = 1. Otherwise go to step 10.

Step 10) If $-ve\ error > E_b$; then G1 = G2= 1 and G3 = G4 =0. Otherwise G1 = G2 = G3 = G4 = 0

Step 11) Check the amplitude of reference signal, does it require update?

Step 12) Update the value of reference current if required, otherwise leave this step

Step 13) If $t \geq T_m$; then reset the value of t. otherwise leave this step.

Step 14) Go to step 4.

When this switching scheme is applied to motor or any other load withdrawing relatively large load current in the beginning than the load current during steady state operation, then system faces a problem with reference signal that the large current in the beginning set a reference with relatively large amplitude than required during the steady state operation. This causes improper operation of system.

This issue is solved by employing the reset logic for reference signal once the current requirement reduced to its normal steady state condition. This reset instruction requires10 to 20 cycles only, depending on the difference between the initial and updated reference signal and it improves the outcome significantly.

IV. RESULT AND DISCUSSION

Simulation and testing has been performed for the developed modified switching scheme on the model of VS source inverter is shown in fig.1. The simulation has been carried out for linear as well as dynamic loading condition. An R–L load is used for linear loading condition while for dynamic loading condition a main and auxiliary winding type motor is used. Simulation is also performed for the PWM switching scheme under same loading condition. The results of both schemes are used for the comparative analysis.

The simulation is performed for the load current of 50 Hz at output terminal. All the waveforms presented in the paper are recorded under steady state condition. The various loading condition and other parameter for simulation is as follows.

1) Source voltage (Vs) = 200V
2) Source impedance (Zs) = 0.1 Ω
3) Modulating index for PWM = 0.8
4) Modulation frequency for PWM = 1.2KHz
5) R–L load = 15+ j9.425 Ω
6) Motor load
   a) Volt-ampere (VA) = 0.25 * 746 watt
   b) Resistance
      # main winding stator = 2.02 Ω
      # main winding rotor = 4.12 Ω
      # auxiliary winding stator = 7.14 Ω
   c) Inductance
      # main winding stator = 7.4e-4 H
      # main winding rotor = 5.6e-3 H
      # auxiliary winding stator = 8.5e-3 H
      # main winding mutual inductance= 0.1772H

A. *Linear load (R –L load)*

The waveform of voltage and current for R–L load obtained using PWM scheme is shown in fig.7 and the voltage and current waveform obtained from modified switching scheme is shown in fig.8. The simulation results obtained for given R–L load for new scheme and PWM are presented in table 1. By observing the waveforms and the result in table 1, a comparative analysis has been done.

The modified switching scheme has given better result than the PWM scheme. The RMS and peak value of voltage and current for the modified scheme is more than that for PWM scheme. The THD (total harmonic distortion) has also shown the

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improvement in case modified switching scheme over the PWM scheme. THD in load current for modified switching scheme is 2.67% and same for PWM is 3.48%. Thus the harmonic content in load current is less in new defined scheme. The THD for voltage is 38.49% for modified switching scheme in comparison of 74.57% of PWM scheme. The analysis of outcome of both schemes signifies that the modified switching scheme gives better result than the PWM scheme for the given load and operating condition.

B. *Dynamic load (Motor load)*

The simulation has been performed for motor load also under the previously defined loading conditions. The waveforms obtained by applying PWM scheme is shown in fig.9 and waveform obtained using modified switching scheme are shown in fig.10. The comparative results of simulation of both the schemes are in table 1.

Similar to the case of R–L load, for motor load also, the modified scheme provides higher RMS and peak value of voltage as well as of current, than the values obtained from PWM scheme. The THD in load current is 4.63% for modified scheme which shows improvement over 5.01% of PWM scheme. The 45.45% THD in voltage from modified switching scheme is also a significant improvement with respect to 77.63% THD from PWM scheme. The reduced value of THD implies lesser amount of harmonics and thus better quality of output power.

V. CONCLUSION

Switching Scheme for Single Phase VS Inverter using value of output current as modulating signal has been developed successfully. The developed scheme has been implemented using SIMULINK facility of MATLAB. The simulation has been performed with linear load as well as with dynamic load to analyze the performance of newly developed switching scheme. The result obtained from new scheme is compared with the result obtained from PWM scheme. The modified switching scheme has shown better results than the PWM scheme in terms RMS value, peak value and THD for current as well as for voltage. Few additional modifications can be made to further improve the outcome. A similar strategy for three phase system is also proposed to be developed in future.

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TABLES AND FIGUERES

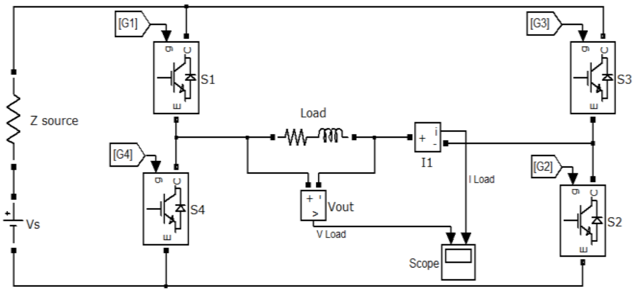

Fig.1 Single phase H-bridge VS DC – AC inverter model

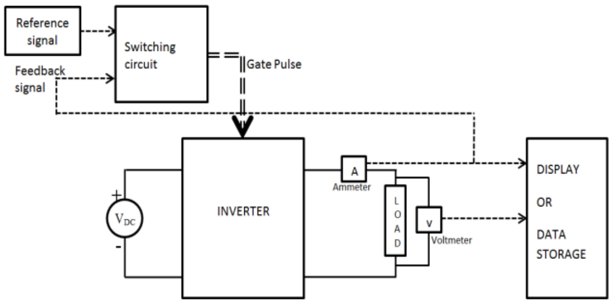

Fig. 2 Block diagram for new switching scheme

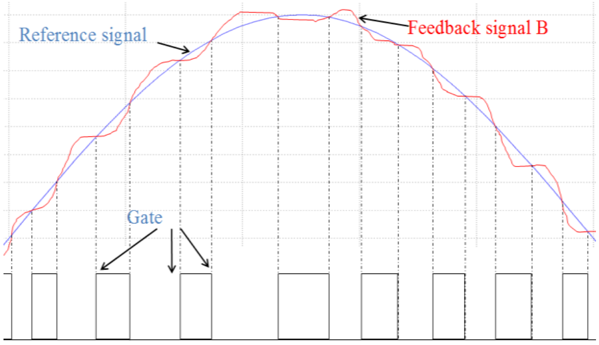

Fig.3 (a) A conceptual plot for new switching scheme

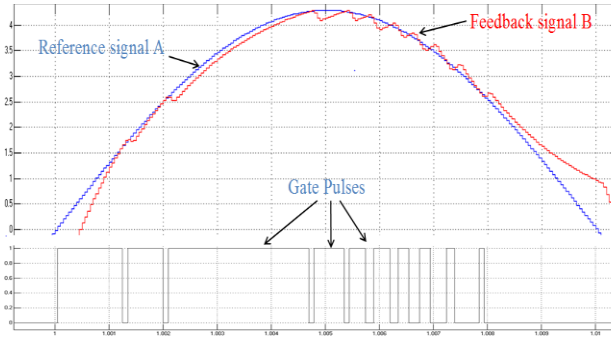

Fig.3 (b) Plot for new switching scheme with practical data

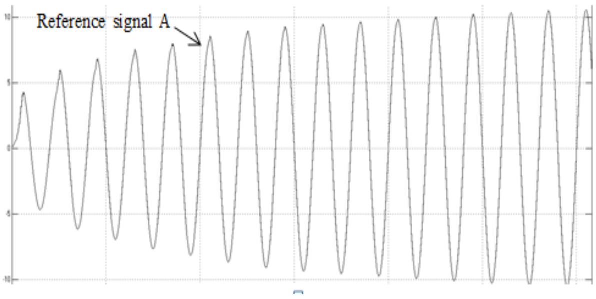

Fig. 4 Reference signal A

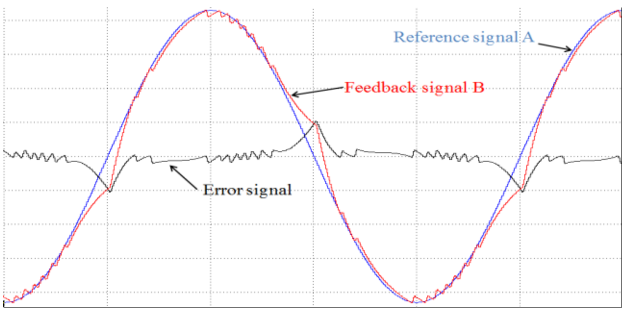

Fig.5 Error signal representation

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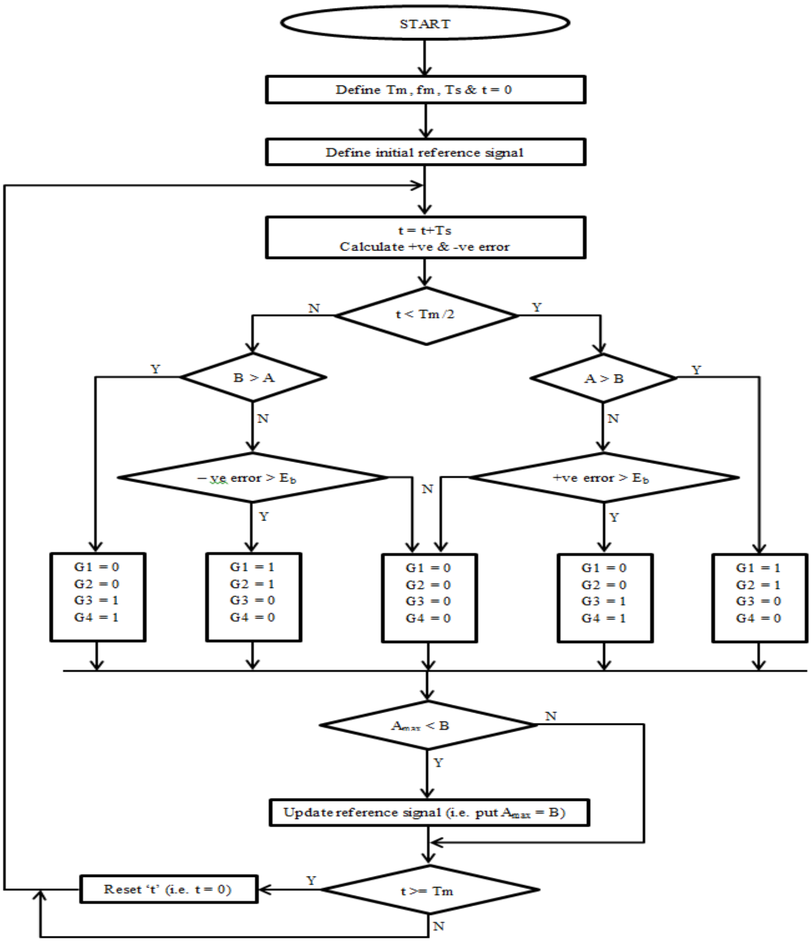
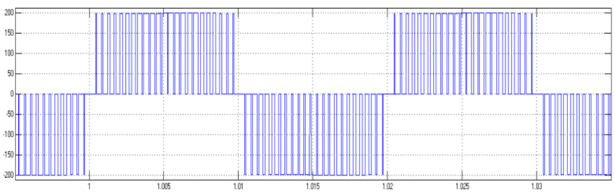
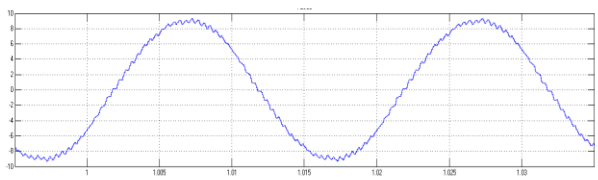


Fig.6 Flowchart for modified switching scheme

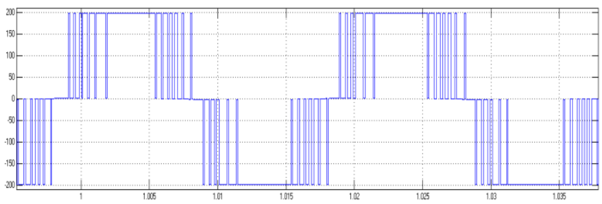


(a)

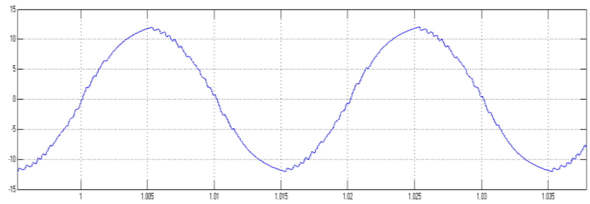


(b)

Fig.7 Single phase H-bridge VS DC–AC inverter test result for R-L load using PWM switching scheme. (a) voltage and (b) current waveform



(a)



(b)

Fig.8 Single phase H-bridge VS DC–AC inverter test result for R-L load using modified switching scheme. (a) voltage and (b) current waveform

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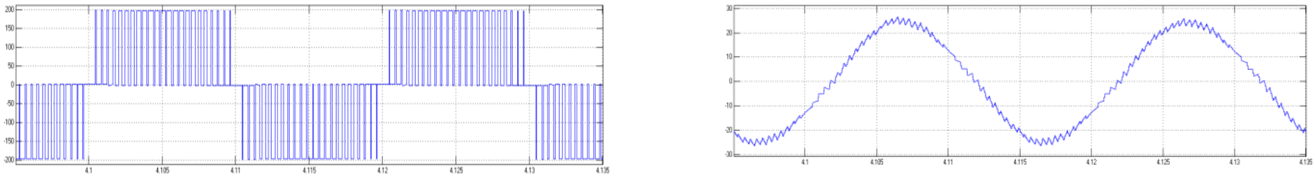
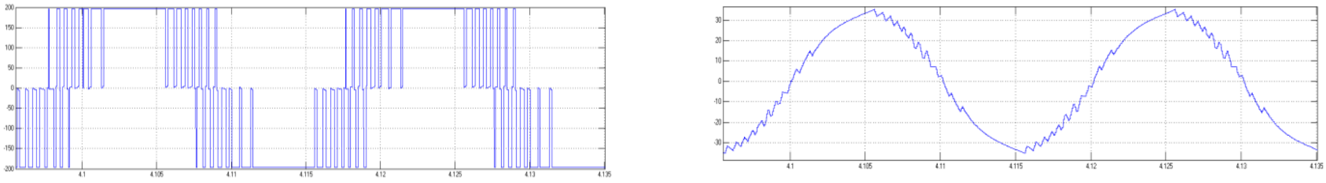


(a) (b)

Fig.9 Single phase H-bridge VS DC–AC inverter test result for motor load using PWM switching scheme. (a) voltage and (b) current waveform



(a) (b)

Fig.10 Single phase H-bridge VS DC – AC inverter test result for motor load using new modified switching scheme. (a) voltage and (b) current waveform

TABLE I. **SIMULATION RESULT FOR VARIOUS LOADS**

Load Types	Parameters	PWM	Modified switching
R–L load	Vrms	116.3 V	148.2 V
	Irms	6.565 A	11.83 A
	Vpeak	164.5 V	209.5 V
	Ipeak	9.284 A	8.364 A
	V THD	74.57%	38.49%
	I THD	3.48%	2.67%
Motor load	Vrms	108.31 V	147.2 V
	Irms	17.48 A	23.77 A
	Vpeak	153.2 V	208.1 V
	Ipeak	24.72 A	33.62 A
	V THD	77.63%	45.45%
	I THD	5.01%	4.63%