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# USDO based Control of Current Sensorless Boost Combined Inverter with Load Variations

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**Abstract:** A current sensorless sliding mode control scheme is developed to remove the effects of mismatched load disturbance and higher order harmonics of a conventional inverter. Normally the problems associated with an inverter is, to maintain the output voltage regulated and there harmonics eliminations. The output voltage is normally affected by the load variations. In case of EV system, the variations range from no load to full load, the control performance also has an impact on these. The input variations are avoided by inserting a dc-dc converter circuit. For the control, to sense the output current, wide band current sensors are required. It will increase the cost of the system as well as the size. This problem is avoided by the observer method. The voltage is observed continuously and is used to develop the inductor current. By integrating the estimations into the design of sliding surface, a current sensorless sliding mode controller is proposed. The simulation of the proposed system is modelled and evaluated with desirable results in MATLAB/Simulink.

**Keywords:** USDO - Universal State Disturbance Observer, SMC-Sliding Mode Control, PWM – Pulse width modulation, EV- Electric vehicle.

## I. INTRODUCTION

The history and evolution of inverter started from 1980s after the invention of a household inverter air conditioner by Toshiba. Development in the area of renewable energy sources and storage elements increased the application level of inverter circuits also the regulation of output voltage with respect to any variations such as load variations tend to improve the feedback circuits. Normally current as well as voltage were sensed from output side for creating the error signal. But the use of current sensor may increase the cost of the system and also make it bulkier. In case of feedback control system output voltage is affected by several disturbance among which the change in load is more severely affected. The load variation will create a varying load current from a smaller to its rated values. So that a current sensor with large current sensitivity is needed. Here we are developing the inductor current for feed-backing from the voltage sensed from the output side. With the help of state space modelling the inductor current is developed.

Normally as a feedback control system PID controllers were commonly chosen which is much simpler than any other controlling schemes but they possess high voltage distortion under non-linear loads. Use of PI controller will also takes more time initially to reach the required output level. Commonly in inverter control systems capacitor current feedback is more suitable than the inductor current feedback since the capacitor current directly reflects any change on the capacitor and thus the output voltage across the load. Here the current is developed through state estimation and current sensorless digital control will reduce the size and cost of the inverter system.[1] The output voltage , input voltage and switch control signal are used to estimate the inductor current with the help of an observer control scheme for accurate voltage regulation with stability under transient conditions. In PI controllers, with small signal modal analysis, small perturbations at equilibrium point will affect the stability of the system. When exposed to small signal disturbances the converter with duty ratio of 50% will result sub harmonic instability. The conventional peak current mode control method has also the disadvantage, which is easy to be exposed to the noise from current sensing process because of the switching occurs at peak of inductor current [2]. Current controlling scheme were achieved mainly through hysteresis band control, predictive current control, and PI control which is in stationary frame needs transition of dq to abc. The uncertainties raised are matched and unmatched uncertainties. The uncertainty acting through the input channel is matched uncertainty while through load variations and through control channel, the unmatched uncertainties. For matched uncertainty SMC is enough, in case of unmatched a combination of the disturbance observer based sliding mode control is used [3]. Most of the research and improvements occurring in the output side control of the inverter, even though the frequency components raised because of the continuous discharging process of the battery due to the switching of the inverter circuits which will reduce the life of the battery. In order to avoid the effect of this switching of inverter directly to the battery a dc-dc converter is introduced in this paper. Even though a converter need to be used at the input side, the system utilizes the application of a boost converter which will produce a gain of voltage level from a low voltage to high level. Such that the frequency components developed due to the switching of the 4 switches present in the bridge inverter has more effect on the output side of the converter. So that the battery life can be improved by avoiding the frequent variations in its operation. The output of the boost side voltage is controlled by a PI controller to avoid the input variations.

Finally the system consist of an input DC – DC converter for reducing the input side variations and an inverter circuit with USDO based sliding mode control for the variations of load which will cause a large change in the current rather than in the voltage mainly for electric vehicle system where the load varies from no load to full load where we require a wide band current sensors.

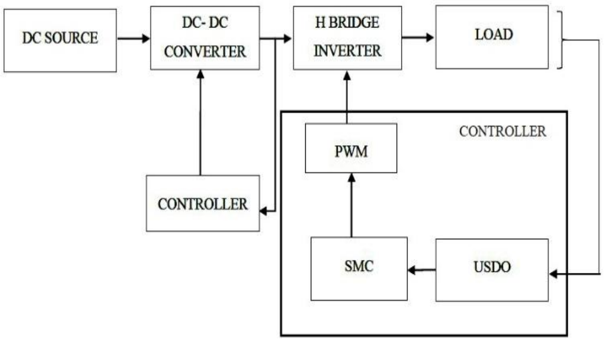


Fig 1. Block diagram of proposed system

Fig.1 shows the overall block diagram for the system in which DC source is representing the input source of direct current which may be solar panels or any other renewable energy sources. On using solar panels further development such as MPPT techniques can also be in corporate with the presented system.

## II. SYSTEM DESCRIPTION

A general structure of the DG system-based renewable energy source consists of three parts: input power, power conversion unit and load. As one of the main components in the energy conversion process, the precision control of the power conversion unit is of particular importance to enable satisfactory performance for the connected loads.

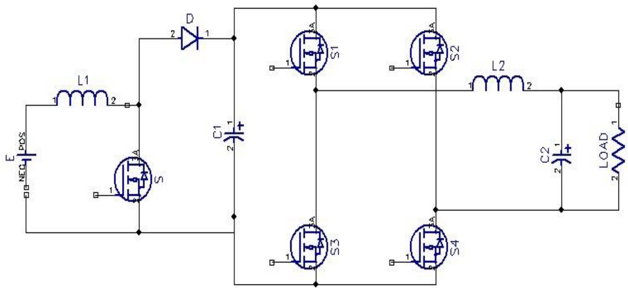


Fig. 2 Circuit diagram of proposed boost combined inverter system

The main circuit of the power conversion unit is a typical PWM based DC-AC inverters are widely used in various kinds of standalone applications. Voltage source inverter (VSI) plays a significant role in this. It consists of an input DC voltage source *E,* boost inductor *L1*, switching device *S* diode *D* filter capacitor at the boost output side *C1* and PWM controlled switching devices a filter inductor *L2*, a filter capacitor *C2*, and a load. The load, which includes the linear resistance load and non-linear R-L load, consumes the power generated from energy sources.

It can be divide into two parts, a boost converter at the input section and a VSI at the output side;

*A. Single phase dc-ac inverter*

The inverter circuits consist of four switches $S_{1-4}$ , those are switched according to pulse width modulation techniques. So that the system output possess effects of the modulation index of the PWM signal generated.

By the application of voltage and current law;

$$\dot{v}_0 = \frac{i_l}{C} - \frac{v_0}{ZC} \qquad (1)$$

Where $v_0$ represents the output voltage nothing but the voltage across the capacitor, $i_l$ the inductor current, C capacitance and Z equivalent output impedance.
From KVL;

$$\dot{i}_l = \frac{E}{L} - \frac{v_0}{L} \qquad (2)$$

E the input voltage to the inverter L inductance, but E is not available for the full period, it depends on the PWM control. Let u represents the duty ratio which varies from [-1, 1] which is nothing but the modulation index then;

$$\dot{i}_l = \frac{uE}{L} - \frac{v_0}{L} \qquad (3)$$

The variation in load is given as a disturbance d(t) in the system control path.

*B. Boost converter*

A simple boost converter of 24 – 150 volt circuit is provided at the input side of the battery to maintain the required level of voltage at the input side and to reduce the input variations which will not directly affects the battery. Considering the boundary condition; equation for duty ratio (D) can be written as

$$\frac{v_{0\_boost}}{v_{in}} = \frac{1}{1-D} \qquad (4)$$

Where $v_{0\_boost}$ represents the output voltage of the boost converter and $v_{in}$ the input voltage from battery. For a fixed value of the capacitor the inductance value is;

$$L_{boost} = \frac{v_{0_{boost}}\, T_s D(1-D)^2}{2I_{0_{boost}\ max}} \qquad (5)$$

## III. PROPOSED SYSTEM

The circuit diagram of the proposed system is shown in figure.2 consist of a boost at the input stage followed by an H bridge inverter. By controlling the boost output voltage the variations in the input side voltage of the inverter can be reduced. The double frequency components raised because of the switching of the inverter will not affect the battery directly because of the presence of dc-dc converter, which consist of only one switch so that the switching frequency component that directly affect the battery will only because of that switch.

The control provided to the boost is normal PI controller, initially the system possess a lag which is predicted even though final output voltage came to a fixed value. The control can be provide through the same microcontroller used for control of the inverter side or it can be realized by means of passive networks. When comes to the inverter side, it's simply a H-bridge inverter but replacing the normal feedback PI controller an observer based system is developed. By means of a universal state and disturbance observer the state, inductor current is developed and in each cycle the variations in the load also being checked with a reference current wave provided at the control circuit. The main objectives of the improved system is to maintain an acceptable THD value by eliminating the third and fifth order harmonics and to maintain the voltage level constant. The paper presents the comparison of the proposed model with the normal PI controller based inverter system.

The state observer and disturbance observer equations are as follows;

$$\dot{\widehat{v_0}} = \frac{i_l}{C} - \frac{v_0}{ZC} + (v_0 - \widehat{v_0})\alpha_1 \qquad (6)$$

$$\dot{\hat{i_l}} = \frac{uE}{L} - \frac{v_0}{L} + (v_0 - \widehat{v_0})\alpha_2 \qquad (7)$$

When the disturbance comes the voltage equation includes a disturbance component $d_1$ which may be corresponding to load variations or for harmonic disturbance.

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## IV. CONTROL OF THE PROPOSED SYSTEM

Sinusoidal Pulse Width Modulation (SPWM) technique is used for switching the inverter circuit, but the sinusoidal signal u(t) for comparing with the reference are generated by means of USDO followed by a SMC. The generated u(t) signal is phase shifted by an angle 180 degree and is compared with the carrier repeating sequence. So that unipolar switching scheme is included in the paper. Unipolar switching scheme with filter circuits give much more reduced THD and perfect output waves than bipolar switching schemes.

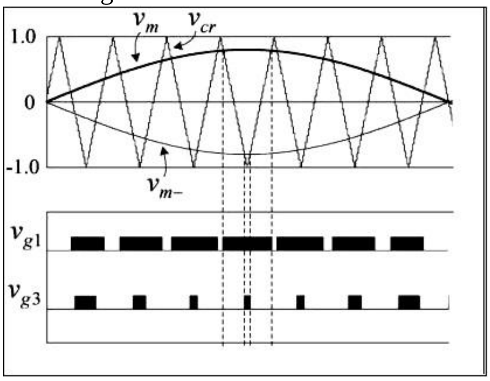


Fig. 3 unipolar PWM technique

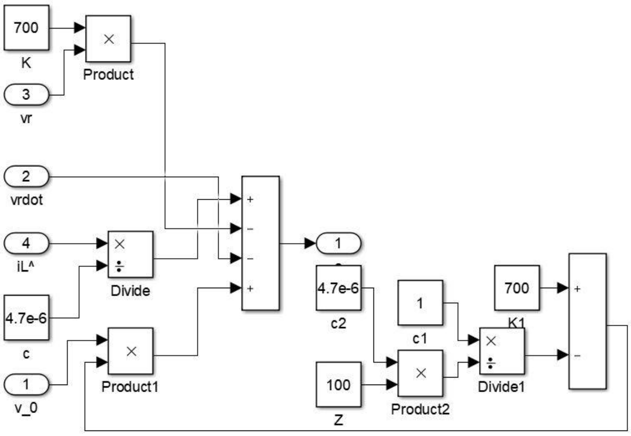


Fig. 4 SMC function MAT LAB block diagram

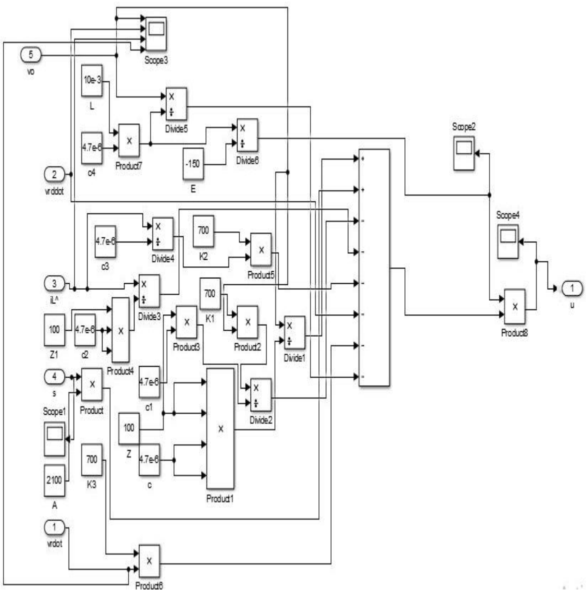

Fig. 5.Duty ratio function generation MATLAB block diagram



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Corresponding equations for the SMC and duty ratio are given by

$$S = \left\{K_1 - \frac{1}{Z_0}\right\} v_0 + \frac{i_l}{C} - k_1 v_r - \dot{v}_r + \hat{d}_1 \qquad (8)$$

$$u = -\frac{LC}{E}\left[\frac{-v_0}{LC} - k_1 \dot{v}_r - \ddot{v}_r - \frac{k_1 \hat{\imath}_l}{C} - \frac{\hat{\imath}_l}{Z_0 C^2} - \frac{k_1 v_0}{Z_0 C} + \frac{v_0}{C^2 Z_0} + \alpha sign(s)\right] \quad (9)$$

When the disturbance comes corresponding $\hat{d}_1$ term will come to the above equation.

## V. SIMULATION RESULTS

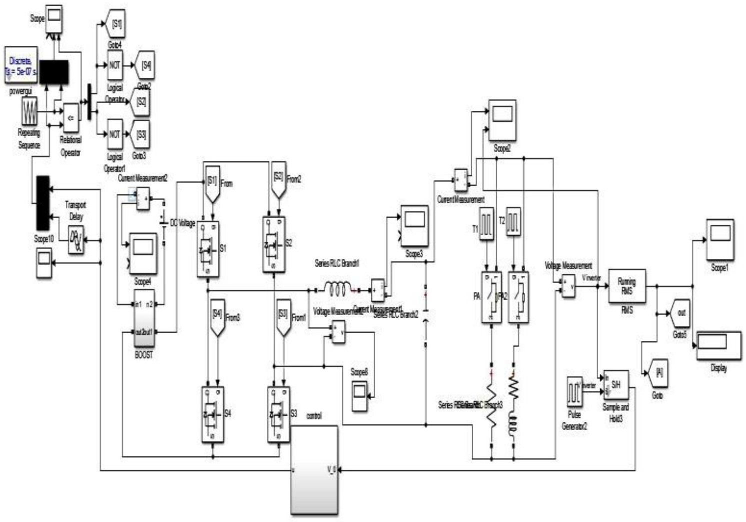

Fig 6.Total power circuit

The proposed system has been simulated and compared with the PI controlled inverter.

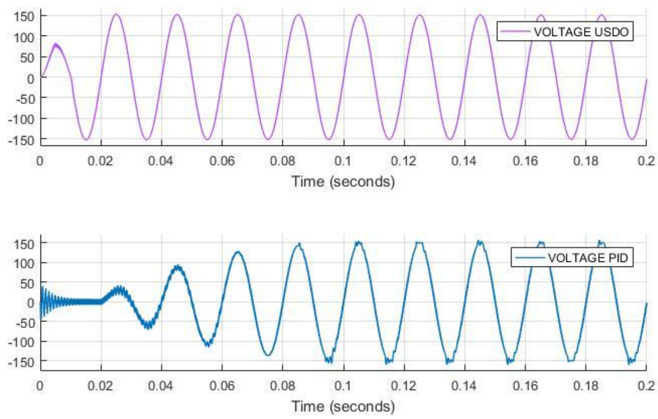


Fig. 6 Comparison between USDO and PID based inverter system

PID controller possess a large time to reach the output voltage level and at the initial stage it possess much more time to reach the required value even without the boost at the input stage.

The output voltage of the system with load variation is shown in figure 6. It shows after the change in load, after the transients in the voltage for a half cycle it comes to the previous value. THD analysis with load variation gives the following table data, the THD is calculated before load change and after load change and avoiding the transient period of the change.

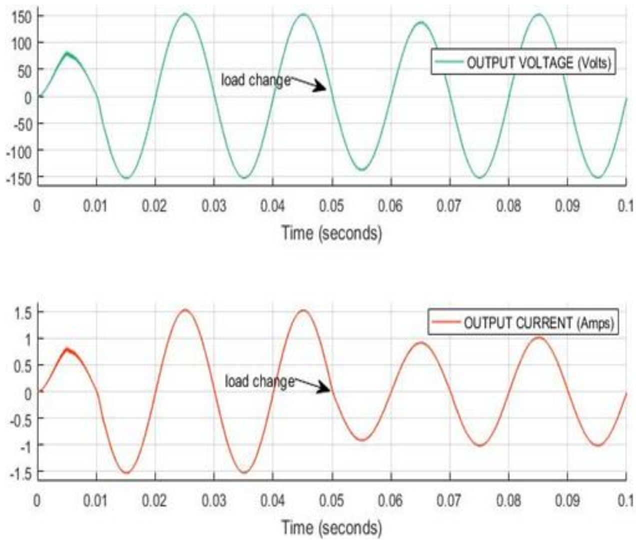


Fig. 6 Output of the USDO based inverter with load variations

Table 1. THD with load variations

| LOAD (W) | THD (%) |
|---|---|
| 100 | 0.42 |
| 75 | 0.44 |

## VI. CONCLUSION

The proposed boost combined DC-AC inverter simulated using MATLAB/SIMULINK and is compared with the normal inverter with PID control. Current sensorless feedback control of the inverter system is achieved so that for a wide range of variation of load systems like EVs the proposed method is more suitable. The input voltage to the system maintained to be constant and the switching effects are not directly affects the battery. In addition to the PID controlled boost converter, installation of a PV panel with MPPT control can also be developed. By extended USDO approach the harmonic components can be directly given to the system as disturbance and is possible to eliminate.

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