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Hybrid PV-Cuk and Swiss-PFC Power Converter System for Industrial Induction Motor Drive Application

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Abstract: General configuration of hybrid power converter requirement is improving power and voltage over load for high power industrial application. This study is proposed photovoltaic based Cuk circuit and AC-grid with Swiss-PFC converter are implemented to improving performance of proposed hybrid converter system such as high power and voltage generation to applying across induction drive DC-link circuit. Introducing of proposed hybrid converter is to provide continuous high power for operating of industrial induction drive. Phase power sensing of vector control is proposed to control of induction motor to operate in desired performance in high power operation whereas hybrid converter is controlled by PFC control and P&O based Maximum Power Point (MPPT) scheme is applied on proposed hybrid converter to operate in high power and high voltage control. The performance of proposed hybrid converter and induction drive control is achieved using proposed control approach and its simulation is been tested using MATLAB/Simulink Software.

Key words: Cuk converter, Swiss converter, Power Factor Crrection (PFC), Induction Motor (IM), vector control, Maximum Power Point Tracking (MPPT)

INTRODUCTION

In industrial application the power electronic converter has high efficiency, high power production and leading current is required. However, in conventional converter have inherent drawbacks of less power factor. In hybrid renewable energy system such as solar and ac source has promising more energy sources among other renewable energy source and produce high power (Moury *et al*., 2016a, b; Pachanpan, 2014; Alam *et al*., 2014). The PV has clean, efficient, pollution less power production. The PV and ac source is fed to the hybrid converter such as Cuk and Swiss converter has high power at the output (Deliu *et al*., 2014; Chen *et al*., 2015).

Flyback converters achieve the power factor and increase the dc voltage compared to the boost converter. In certain limits can achieve the PF and switches are turned on at zero crossing switches and has switching losses are reduced. The flyback converter converts the ac to dc through single, two stage flyback PFC converters. The two stage converter has complex, less efficiency. The flyback converter produces more dc power at the output but it is used in low power application device (Tung and Chung, 2016; Lin *et al*., 2011; Quang *et al*., 2013). The SEPIC converter has less torque ripple, high power density when operating switching frequency is high. A single ended primary inductor converter based PFC control the dc link voltage compared two stage converters. The SEPIC converter has high power factor, less amount of dc voltage, less efficiency and has high cost (Sarankumar and Murugan, 2015; Foroozeshfar *et al*., 2014; Keipour *et al*., 2012).

In high power application the power quality of the induction motor will be high such as power factor correction and leading current. The THD is the ratio of harmonic voltage to fundamental voltage. The power factor is increased (unity) when the input voltage supply is purely resistive (no reactive power). The Cuk converter fed induction motor for power factor correction has low switching losses compared to the other conventional converter. The conventional converter has high switching PWM signal will increase the switching losses. In Cuk converter operation will be similar to buck boost converter but the output current or voltage will be continuous. The proposed converter has step up operation. The Cuk converter has high efficiency, easy to implement the transformer isolation, low current ripple and operates in both continuous and discontinuous modes of operation (Krishnan *et al*., 2016; George and Raj, 2016; Suryoatmojo *et al*., 2016; Crisbin and Sasikumar, 2016; Bodetto *et al*., 2015).

In proposed Swiss converter fed induction motor for PFC has to improve the leading current of the motor,

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regulate the DC link voltage and has high power factor. The hybrid energy source such as solar and ac produce high power and use the hybrid converter such as Cuk and Swiss. The hybrid converter used to maintain the high power dc link voltage and feed into the induction motor. The control of induction motor is implemented using three-phase inverter circuit followed by applying vector control scheme to maintain desired motor performance.

MATERIALS AND METHODS

Proposed converter structure: The proposed hybrid converter is feed into the three phase high power induction motor. The AC and solar is the primary source of the circuit and the solar energy is feed into the Cuk converter and the ac supply is directly feed into the Swiss converter and the output of the Swiss is further boosted by using the boost converter. The proposed circuit configuration is shown in Fig. 1.

The MPPT has used to extract the maximum power from the PV cell. The MPPT algorithm can send the signals to the dc-dc converter to produce the pulse can control the duty cycle of the converter. Thus, the converter can generate the maximum power and also the dc link voltage is regulated. The hybrid converter Cuk and Swiss maintain the dc link voltage and improve the power factor correction. The induction motor based hybrid converter has low power factor and lagging current. The drawback is removed by the proposed circuit configuration.

Modeling of solar cell: The proposed solar power generation has nonlinear power can change with the environmental condition, less maintenance and cost effective. The voltage produced from the PV cell depends on the semiconductor used and also varying temperature, insulation, etc. The PN junction absorbs the radiation and forms the electron hole pair. Thus, the light energy is converted to electrical energy. The single diode PV module is shown in Fig. 2. In PV the current source indicate the light generate the current:

$$I_{diode} = I_o\left(-1+e^{\frac{qV}{KT}}\right) \quad (1)$$

Where:

I_o = Saturation current
V = Applied voltage
K = Boltzmann constant
T = Temperature
Q = Electron charge

The single diode PV model.

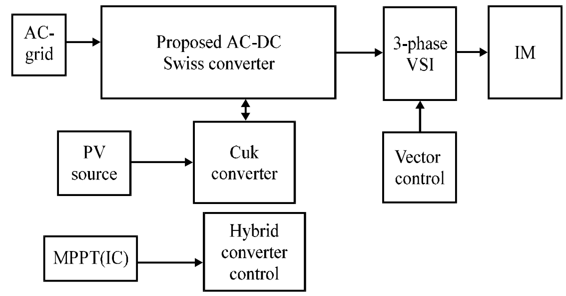

Fig. 1: Proposed circuit configuration

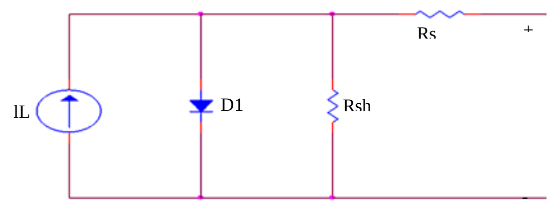

Fig. 2: Single diode photovoltaic equivalent circuit

Operation of proposed system: The proposed hybrid converter is performed for power factor correction and high efficiency. The output of the solar is connected as input of the Cuk and ac source is feed into the Swiss converter. The proposed hybrid converter circuit is operated in different modes. The proposed hybrid converter is shown in Fig. 3.

In hybrid power, one power is not present and the other will be working in normal operation. Both are present they can be operated in different modes. The PV source alone present the diode D_2 turn off and the diode D_1 always turn on.

Modes of operation: Mode 1:

$$\left(0<t<d_1T_s\right)$$

Both Cuk converter and Swiss converter are on. The average PV current is and is the current from the ac source. In Cuk converter the switch M_1 on. The current flows in the inductor is:

$$I_{L1} = I_{pv}+\frac{V_{pv}}{L_1}t \quad (2)$$

$$I_{L2} = I_{dc}+\left(\frac{V_{c1}+V_{c2}}{L_2}\right)t \quad (3)$$

In Swiss converter switch S1, S4, S5 are on and the remaining switches S2, S3, S6 are off. The positive cycle of Swiss voltage is present across the load of the hybrid converter.

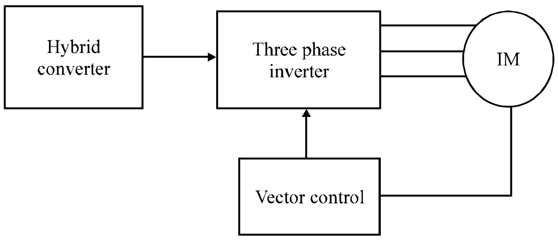

Fig. 3: Proposed control diagram for induction motor using hybrid converter scheme

Mode 2: The Cuk converter on and the Swiss converter is off. The current flow in the Cuk converter is.

Mode 3: The Cuk converter OFF and the Swiss converter is ON. The switch S2, S3, S6 is ON and the switch S1, S4, S5 is OFF. The negative cycle of Swiss voltage will emerge across the load of hybrid converter.

Mode 4: Both Cuk and Swiss converter is ON or Swiss ON whereas Cuk converter OFF.

Induction motor control: In induction motor has used in high power application and has low cost, easy maintenance. The Cuk and Swiss converter produce high power and feed into the three phase inverter which is shown in Fig. 3.

Vector control of induction motor: Direct torque flux control method is used to control the torque and flux of the motor. By comparing the actual and reference value the torque and flux will be feed into the PI controller. The DTC has lower dependency parameter, robust, easy implementation and has easy to control the motor parameter. In induction motor the torque ripple induce the error in the sensor less control of the motor drives and also increase the current ripple and has high EMI. So to reduce the torque ripple by using the vector control DTC based SVM (Daut *et al*., 2011; Zabihi and Gouws, 2014; Moury *et al*., 2016b; Tamrakar and Malik, 1999; Sadhwani and Ragavan, 2016).

The proposed control circuit which is control of direct torque control based space vector modulation the voltage and current of inverter is converted to dq axis is shown in Fig. 4. The torque and flux is calculated by the voltage and current of the dq axis. The torque and flux equation is explained in Eq. 1-4:

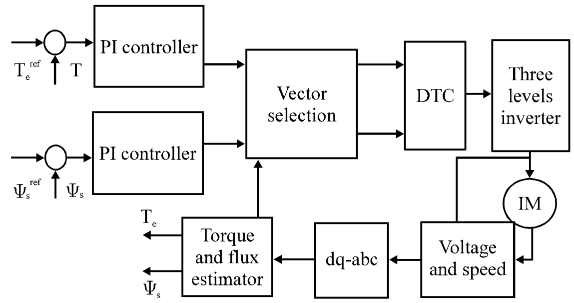

Fig. 4: Proposed vector of induction using hybrid PV-Cuk and Swiss-PFC converter scheme

$$T_e = \frac{3}{2}\frac{P}{2}\left(\psi_{ds} i_{qs} - \psi_{qs} i_{ds}\right) \tag{4}$$

$$\psi_{ds} = \int \left(V_{ds} - r_s i_{ds}\right) dt \tag{5}$$

$$\psi_{qs} = \int \left(V_{qs} - r_s i_{qs}\right) dt \tag{6}$$

$$\theta = \tan^{-1}\left(\frac{\psi_{qs}}{\psi_{ds}}\right) \tag{7}$$

RESULTS AND DISCUSSION

Simulation implementation: The proposed hybrid configuration of PV-Cuk and Swiss-PFC converter can able to provide high voltage and high power across DC-link of inverter circuit to operate and control of induction motor. The given hybrid converter fed with vector controlled based induction motor is implemented using MATLAB/Simulink Software to verify about performance and control of both hybrid converter and motor which is shown in Fig. 5. Two major power sources uses for hybrid converter circuit, photovoltaic power sources uses via Cuk converter where as AC-grid power sources is applied through Swiss-PFC converter to improve high power extraction of PV is shown in Fig. 6 and improved performance of AC-grid is shown in Fig. 7, respectively. The combined operation using hybrid integrated circuit by PFC and P&O based MPPT is applied to get high step up voltage and power is drawn in Fig. 8. The 1100 V and 5 kW capacity of induction motor used to verify about industrial drive performance. Corresponding motor performance are drawn in Fig. 9. The parameters used for proposed circuit and motor are tabulated in Table 1.

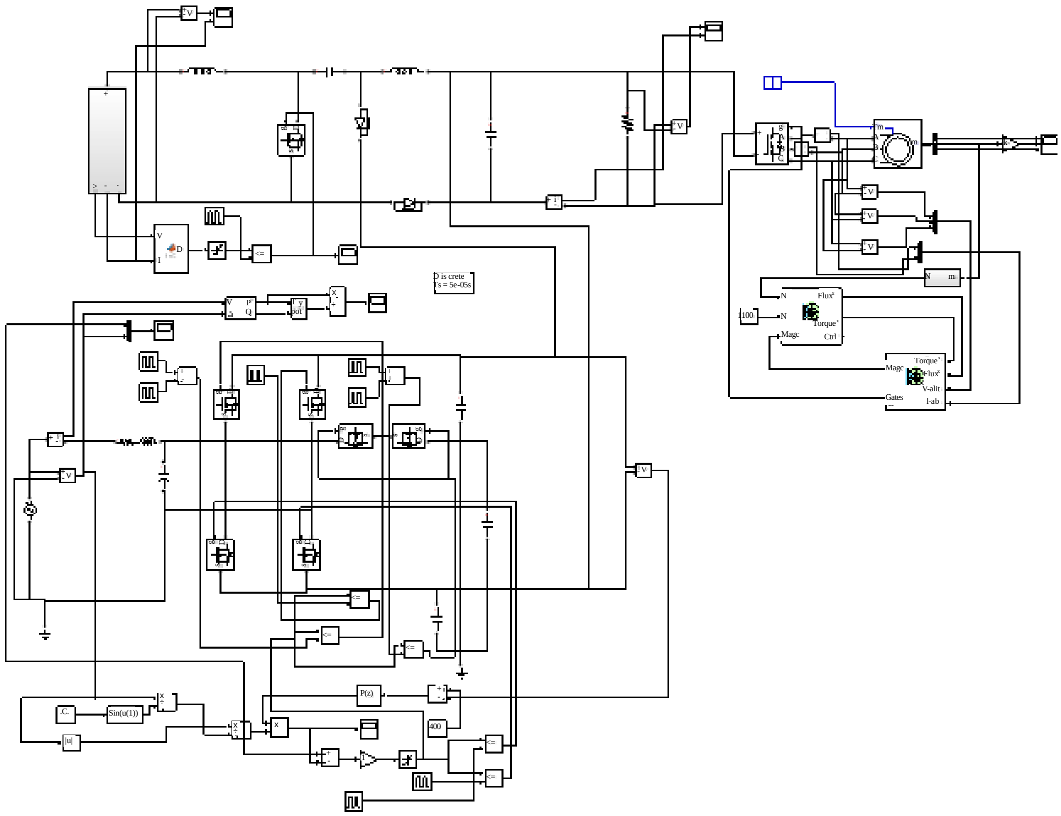

Fig. 5: Simulation implementation circuit for hybrid Cuk-Swiss fed induction motor control

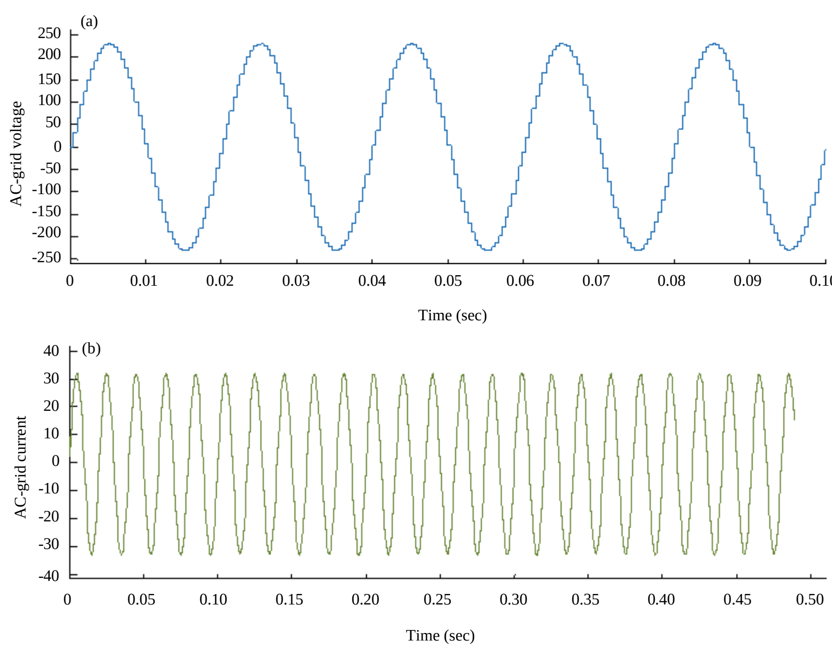

Fig. 6: AC-Grid power performance: a) Voltage (V) and b) Current (A)

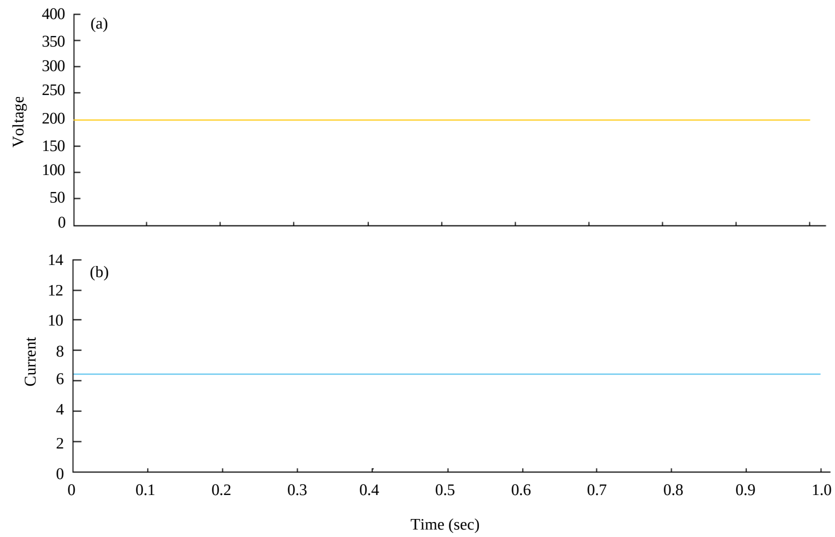

Fig. 7: PV Power performance: a) Voltage (V) and b) Current (A)

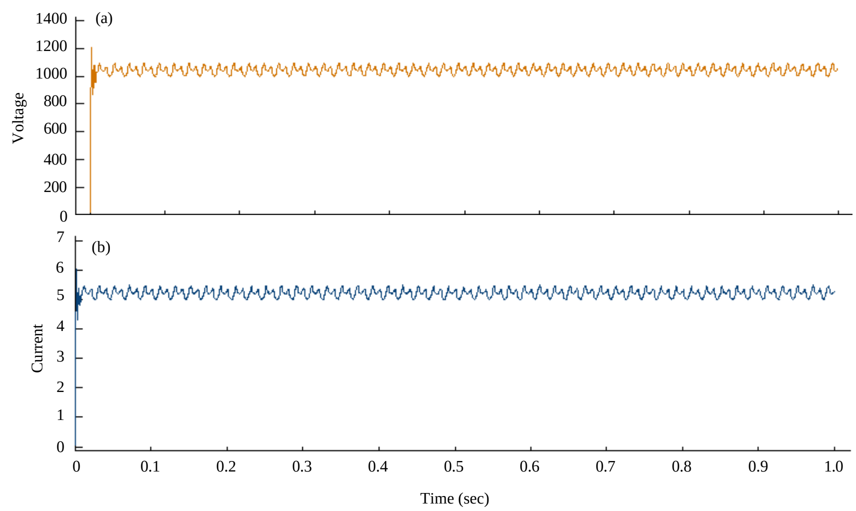

Fig. 8: Proposed hybrid PV-Cuk and Swiss-PFC power performance: a) Voltage (V) and b) Current

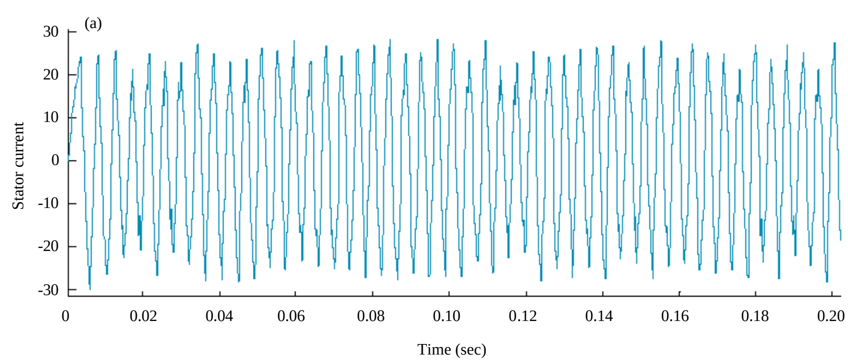

Fig. 9: Continue

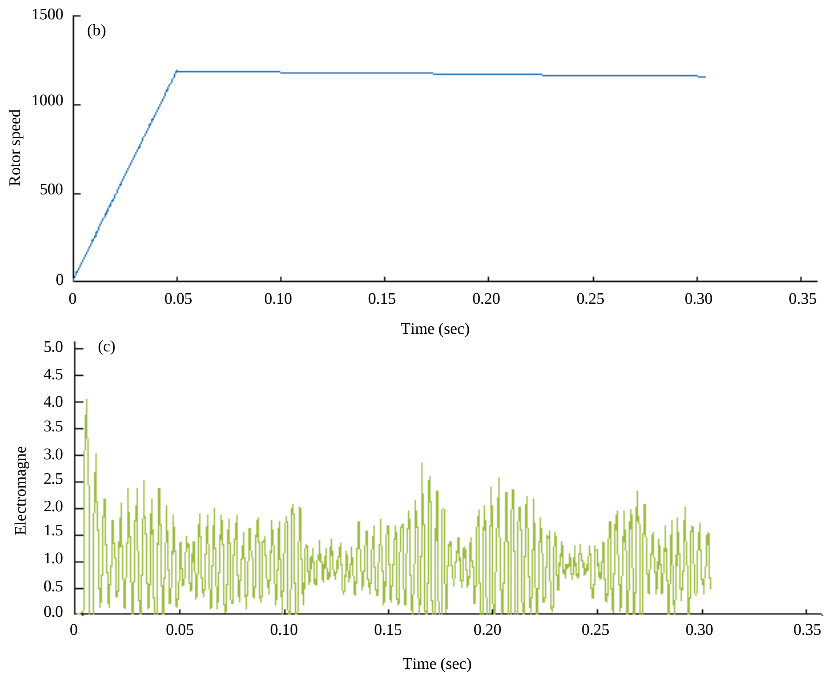

Fig. 9: Proposed motor performance: a) Stator current (A); b) Rotor speed (RPM) and c) Electromagnetic torque (N-m)

Table 1: PV-Cuk converter specification

Name	Values
V_{PV} (V)	200 V
P_{PV} (W)	1.2 kW
I_{PV} (A)	6 A
L_{i1}	432 μH
C_{i1}	17.8 μF
L_{i2}	649 μH
C_0	3.8 μF
Swiss-PFC converter	
V_{Grid} (V)	230 V
P_{Grid} (W)	7 kW
L_i	300 μH
C_i	150 μF
C_1, C_2, C_3	4.4 μF
R_L	200 Ω
P_0	8.2 kW
Induction motor	
Power	5k W
Frequency	50 Hz
Poles	2
Stator resistance	0.9 Ω
Stator inductance	8.8 mh
Inertia	0.1 J (kg.m^2)

CONCLUSION

This study is proposed hybrid PV-Cuk and AC-grid Swiss-PFC converter are implemented to control and operation of industrial induction motor. Perturb and Observer (P&O) based MPPT has produce maximum power from PV source using Cuk converter circuit whereas Swiss-PFC converter is used to regulate an AC-grid power to proposed hybrid circuit. The both generation of power converter is to form a hybrid circuit and its gives a high voltage and high power source and also gives a continuous power across DC-link of inverter. The proposed induction motor is controlled by direct torque control based vector control which is used to maintain desired speed and torque performance using Hybrid power supply system. An 1100 V/5 kW, capacity of induction motor is proposed in this study using hybrid converter supply. A proposed circuit and control scheme was implemented using MATLAB/Simulink Software and verified about their performance of both hybrid converter and motor performance.

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