

STANDALONE BATTERY LESS SOLAR PV BASED INDUCTIONMOTOR CONTROL WITH SPACE VECTOR MODULATION

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Abstract—In this paper conventional DTC scheme has been applied for controlling an Induction motor. It has been simulated in stationary d-q reference frame and its free acceleration characteristics are drawn. Conventional DTC scheme has been simulated with a 5HP, 440V, 50Hz induction motor. Literature review has been done to study the recent improvements in DTC scheme. The space vector modulation technique (SVPWM) is applied to the inverter control in the vector control based induction motor drive system, thereby dramatically reducing the torque ripple. Furthermore the MATLAB / Simulink simulation has been done using a polycrystalline solar PV module supplying power to the motor. In order to reduce the starting current and boost the output voltage from the solar modules an Two Inductor Boost Converter (TIBC) has been used as a voltage booster between the Voltage Source Inverter and the Solar MPPT circuit.

IndexTerms—Direct Torque Control (DTC), Induction Motor, Space Vector Modulation (SVM), Solar PV, Two Inductor Boost Converter (TIBC), MATLAB/SIMULINK.

I. INTRODUCTION

PV is increasingly more cost-effective compared with either extending the electrical grid or using generators in remote locations. It is common to use kerosene, diesel or propane to power generators in agricultural operations. Lack of electricity is one of the main hurdles in the development of rural India. India's grid system is considerably under developed, with major sections of its populace still surviving off-grid. Hence, in the Indian scenario stand-alone solar systems are gaining an increasing interest and they are becoming a very competitive solution, particularly because many sunny days are available throughout the year. Moreover, environmental issues such as population and global warming effects are driving researchers towards the development of renewable energy sources including solar systems. One of the most important applications of PV standalone systems is for water pumping, particularly in rural areas that have a considerable amount of solar radiation and have no access to national grids. A number of experimental dc motor driven PV pumps are already in use in several parts of the world, but they suffer from maintenance problems due to the presence of the commutator and brushes. Hence a pumping system based on an

Induction Motor (IM) can be an attractive proposal where reliability and maintenance-free operations are important.

II. PROPOSED SCHEME

In the middle of 80s new strategies for the torque control of induction motor was presented by I. Takahashi and T. Noguchi as Direct Torque Control (DTC). However, classical DTC has several disadvantages, from which most important is variable switching frequency. Recently, from the classical DTC methods a new control techniques called Direct Torque Control – Space Vector Modulated (DTC-SVM) has been developed. In this new method disadvantages of the classical DTC are eliminated. Basically, the DTC-SVM strategies are the methods, which operates with constant switching frequency. Presented DTC-SVM technique has also simple structure and provide dynamic behavior comparable with classical DTC. However, DTC-SVM method is characterized by much better parameters in steady state operation. Therefore, the following thesis can be formulated: “The most convenient control scheme for Solar PV fed voltage source inverterfed induction motor drives is direct torque control with space vector modulation DTC-SVM”.

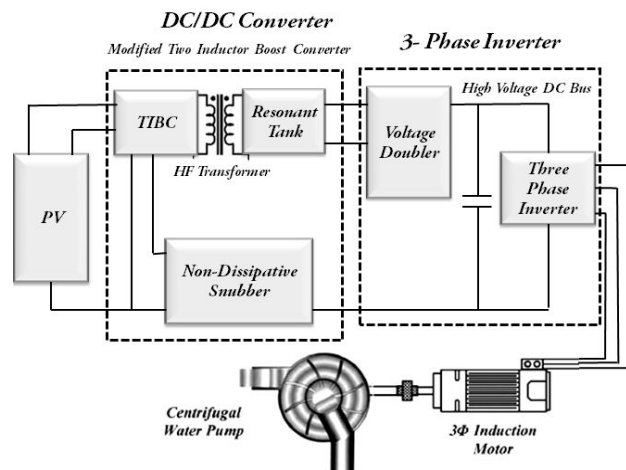


Fig 1. Block Diagram

III. TWO INDUCTOR BOOST CONVERTER

To ensure low cost and accessibility of the proposed system, it was designed to use a single PV module fig.1 presents an overview of the proposed system. The energy produced by the panel is fed to the motor through a converter with two power stages: a dc/dc two-inductor boost converter (TIBC) stage to boost the voltage of the panels and a dc/ac three-phase inverter to convert the dc voltage to three-phase ac voltage. The required dc/dc converter for this kind of system needs to have a large voltage conversion ratio because of the low-voltage characteristic of the PV panels and small input current ripple so that it does not cause oscillation over the maximum power point (MPP) of the Module, thus ensuring the maximum utilization of the available energy. The commonly used isolated voltage-fed converters normally have a high input current ripple, which forces the converter to have large input filter capacitors. These are normally electrolytic, which are known to have a very small lifetime and thus affect the overall life span and mean time before failure of the converter. In this paper, the use of a modified TIBC for the first-stage dc/dc converter is proposed, due to its very small number of components, simplicity, high efficiency, easy transformer flux balance, and common ground gate driving for both switches. The input current is distributed through the two boost inductors having its current ripple amplitude halved at twice the PWM frequency. This last feature minimizes the oscillations at the PV module operation point and makes it easier to achieve the MPP. The TIBC can be modified to a multi resonant converter by adding a capacitor at the transformer's secondary winding. A multi resonant tank is formed by the magnetizing inductance of the transformer, its leakage inductance, and the added capacitor. The intrinsic winding capacitance of the transformer is included in the resonant capacitor. By adding this capacitor and using the parasitic components of the transformer to create the resonant tank, it is possible to achieve ZCS condition for the input switches and output rectifying diodes, and this enables the converter to operate at high frequencies with greater efficiency. With the use of a voltage doubler rectifier at the secondary side of the transformer, as shown in Fig. 2.5 it is possible to reduce the transformer turns ratio, the necessary ferrite core, and the voltage stress on the IGBTs to half of the original ones. As a result, the transformer is cheaper, the IGBTs are cheaper, and the number of diodes in the secondary side is halved.

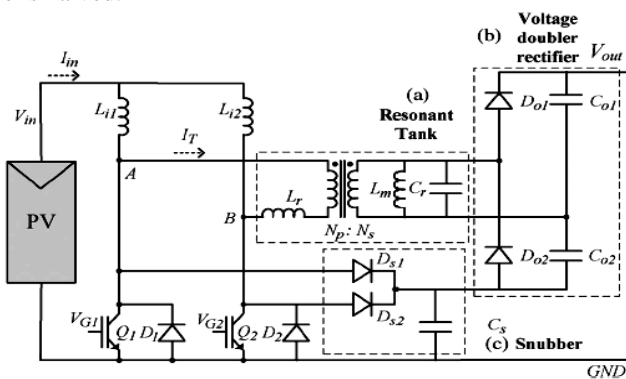


Fig 2. Modified TIBC Topology: (a) Resonant Tank, (b) Voltage Doubler Rectifier (c) Snubber

A. Operating Principle

Matlab Simulink simulation is used to show that, despite the simplicity of the design methodology, the correct operation of the converter is guaranteed, particularly the soft switching of the primary switches for the whole operating load range. Although the resonant process affects the output voltage, depending on the resonant tank component values and the load, this can be neglected because of its small influence and complex effect. Thus, neglecting the resonant effect over the output voltage, including the voltage doubler rectifier and the snubber connecting the primary and the secondary side of the converter, the static voltage gain (K_v) of the converter is defined as:

$$\frac{V_{out}}{V_{in}} = K_v = \frac{1}{1-D} (2\frac{N_s}{N_p} + 1) \quad (1)$$

Where D represents the duty cycle of each switch and must be higher than 50% to guarantee the necessary overlapping for the correct operation. N_s/N_p represents the transformer turns ratio. According to Yuan et al. [24], to minimize the influence of the load on the resonant process on the primary current commutation interval, the switching frequency (F_{sw}) should be higher than the resonant frequency (F_{rs}) of L_m and C_r by a value of at least 1.1. Thus,

$$F_{rs} = \frac{1}{2\pi\sqrt{L_m C_r}} \leq \frac{F_{sw}}{1.1} \quad (2)$$

During the primary current commutation interval, when both switches Q_1 and Q_2 are turned on, inductor L_r participates on the resonance in parallel with L_m and C_r ; thus, the resonant frequency for this interval is defined as

$$F_{rp} = \frac{1}{2\pi\sqrt{\frac{L_m L_r}{L_m + L_r} C_r}} \quad (3)$$

Considering that L_m represents the magnetizing inductance and L_r represents the leakage inductance, then L_m is much larger than L_r ; thus, (3) can be simplified to

$$F_{rp} = \frac{1}{2\pi\sqrt{L_r C_r}} \quad (4)$$

The duration of the commutation interval is equal to the overlapping time (T_{ov}) of the pulse driving signals and can be calculated as:

$$T_{ov} = \frac{(D-0.5)}{F_{sw}} \quad (5)$$

The whole resonant process of the primary switches has the duration of half a resonant cycle. To guarantee the ZCS condition for the entire load range, the following conditions must be satisfied:

$$T_{ov} = \frac{\pi}{\omega_r} \quad (6)$$

$$F_{rp} = \frac{F_{sw}}{2D+1} \quad (7)$$

Another important constraint is the energy accumulated in C_r at the beginning of the primary switching resonant process. This energy needs to be completely transferred to the leakage inductance L_r during this process. From this condition, the following equation is derived

$$L_r \leq \frac{V_0^2}{2I_{in}^2} C_r \quad (8)$$

IV. DIRECT TORQUE CONTROL

The Direct torque control (DTC) technique has been recognized as the simple and viable solution to achieve precise and quick torque response, and reduction of the complexity of field oriented control. This technique is based on decoupled control of torque and stator flux and today it is one of the most actively researched control techniques where the aim is to control effectively the torque and flux.

A. Principle of DTC scheme

The basic principle of DTC is to directly select stator voltage vectors according to the torque and flux errors which are the differences between the references of torque and stator flux linkage and their actual values. The governing equation for torque for this scheme is due to the interaction of stator and rotor fields. Torque and stator flux linkage are computed from measured motor terminal quantities i.e. stator voltages and current. An optimal voltage vector for the switching of VSI is selected among the six nonzero voltage vectors and two zero voltage vectors by the hysteresis control of stator flux and torque.

B. Direct Flux Control

In stationary reference frame the stator flux equation can be written as:

$$\bar{\Psi}_s = \int (\bar{v}_s - \bar{i}_s R_s) dt \quad (9)$$

If the stator resistance drop is neglected for simplicity, the stator flux varies along the direction of applied voltage vector and the equation will be reduced to

$$\Delta \bar{\Psi}_s = \bar{v}_s \Delta t \quad (10)$$

Which means, by applying stator voltage vector \bar{v}_s for a time increment Δt , $\bar{\Psi}_s$ can be changed incrementally. The command value of the stator flux vector $\bar{\Psi}_s^*$ follows a circular trajectory, the plane of stator flux is divided into six sectors as shown in fig.3. Each sector has a different set of voltage vector to increase or decrease the stator flux. The command flux vector rotates in anticlockwise direction in a circular path and the actual stator flux vector $\bar{\Psi}_s$ tracks the command flux in a zigzag path but constrained to the hysteresis band which is shown in fig. 3.

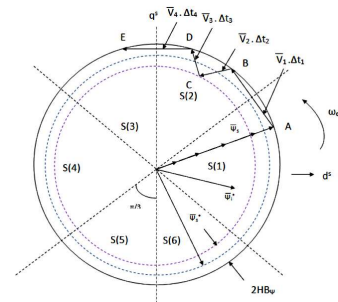


Fig 3. Command Flux

In general the active forward voltage vectors ($V_{s,k+1}$ and $V_{s,k+2}$) are applied to increase or decrease the stator flux respectively when the stator flux lies in sector k . The radial voltage vectors ($V_{s,k}$ and $V_{s,k+3}$) which quickly affect the flux are generally avoided. The active reverse voltage vectors ($V_{s,k-1}$ and $V_{s,k-2}$) are used to increase or decrease the stator flux in reverse direction.

C. Direct Torque Control

The electromagnetic torque produced due to interaction of stator and rotor flux is given by the following equation:

$$T_e = \frac{3}{2} \left(\frac{P}{2} \right) \frac{L_m}{L'_s L_m} \bar{\Psi}_s * \bar{\Psi}_r = \frac{3}{2} \left(\frac{P}{2} \right) \frac{L_m}{L'_s L_m} \Psi_s \Psi_r \sin \gamma \quad (11)$$

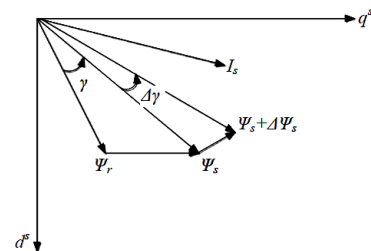


Fig. 4. Stator flux, rotor flux and stator current vectors in d_s - q_s reference plane

From the above equation it is clear that torque varies directly as angle between stator flux and rotor flux i.e. γ . So in order to obtain high dynamic performance it is required to vary γ quickly. Assuming the rotor is rotating in anticlockwise direction continuously and stator flux lies in sector k , the active forward voltage vectors ($V_{s,k+1}$ and $V_{s,k+2}$) are applied to increase γ so as the torque T_e . The radial voltage vectors ($V_{s,k}$ and $V_{s,k+3}$) are used to decrease γ and T_e . By applying the reverse active voltage vectors ($V_{s,k-1}$ and $V_{s,k-2}$) torque can be decreased rapidly. The two zero voltage vectors ($V_{s,0}$ and $V_{s,7}$) are applied to maintain the flux constant ideally and to decrease the torque slightly.

D. Switching Selection

A high performance torque control can be established due to the decoupled control of stator flux and torque in DTC. Fig.5. shows an example of stator flux located in sector-1 (S(1)) with the corresponding optimum switching voltage vectors for anti-clockwise and clockwise rotation of the shaft.

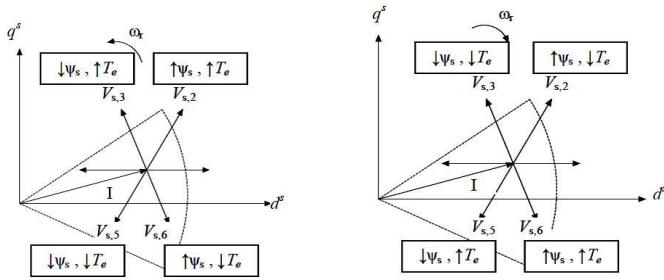


Fig. 5. Optimum switching voltage vector in sector-1 for (a) anti-clockwise and (b) clockwise

Optimum switching vector selection table given by table 1. shows the optimum selection of the switching vectors in all sectors of the stator flux plane. This table is based on the value of stator flux for counter-clockwise rotation of the shaft [8].

$d\psi$	dTe	S(1)	S(2)	S(3)	S(4)	S(5)	S(6)
1	1	V_2	V_3	V_4	V_5	V_6	V_7
	0	V_7	V_0	V_7	V_0	V_7	V_0
	-1	V_6	V_1	V_2	V_3	V_4	V_5
0	1	V_3	V_4	V_5	V_6	V_7	V_2
	0	V_0	V_7	V_0	V_7	V_0	V_7
	-1	V_5	V_6	V_7	V_2	V_3	V_4

Table 1. Optimum switching vector selection table

V. SPACE VECTOR MODULATION

The conventional PWM techniques are suitable for open loop control, but for the implementation of a closed loop controlled AC drive Space vector PWM (SVPWM) technique is applied. In this technique, the switching patterns for the bridge inverter are generated from the knowledge of stator voltage space Phasor. A reference voltage vector is generated to generate a field synchronous with the rotating voltage vector by utilizing the different switching states of a three phase bridge inverter. The three phase bridge inverter has eight possible switching states: six active and two zero states. The six switches have a well-defined state ON or OFF in each configurations. At a particular instant, only one switch in each of the three legs is ON. Corresponding to each state of the inverter, there is one voltage space vector. For example for state zero it is V_0 , for state 1 it is V_1 and so on. These switching state vectors have equal magnitude but 60° apart from each other [8]. These vectors can be written in generalized form as follows:

$$v_k = v_{dc} e^{j\left(\frac{k-1}{3}\right)\pi} = 0 \quad k = 1, 2, \dots, 6 \quad k = 0, 7$$

Where k = inverter state number.

V_{dc} = dc link voltage of the inverter

The inverter state vectors can be drawn as shown in fig.6.

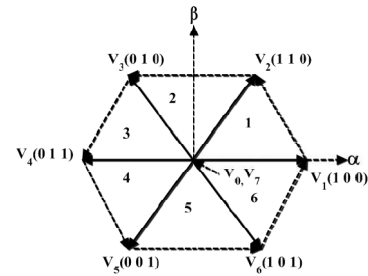


Fig.5. Inverter switching state vectors

VI. RESULTS AND ANALYSES

A. Output of TIBC

From fig 6, it can be clearly seen that the output voltage of the TIBC is fairly boosting and regulating the voltage level at 620 Volts which is the peak value of the output three phase voltage of the Inverter.

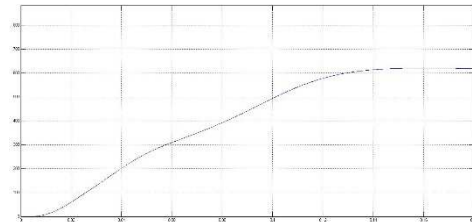


Fig 6. Output Voltage of Two Inductor Boost Converter

B. Output of Space Vector Pulse Width Modulation

The SVPWM output pulse corresponding to phase A is shown in fig 7.

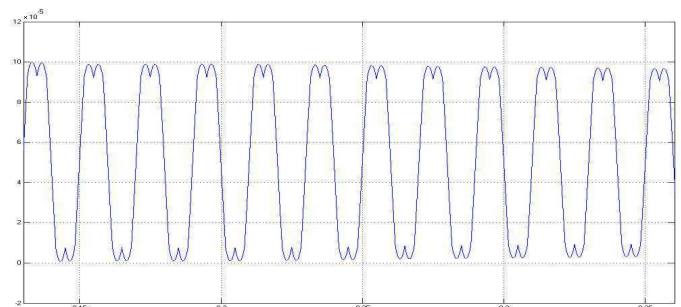


Fig 7. Output of SVPWM corresponding to phase A

C. Output of Voltage Source Inverter

The output voltages of the inverter feeding the induction motor is shown in the fig 8. It can be clearly seen that the three phase line to line voltage is gradually increased in order to facilitate the soft start-up of the induction motor and once the motor has built a sufficient back emf the rated 3 phase rms voltage of 440V is supplied.

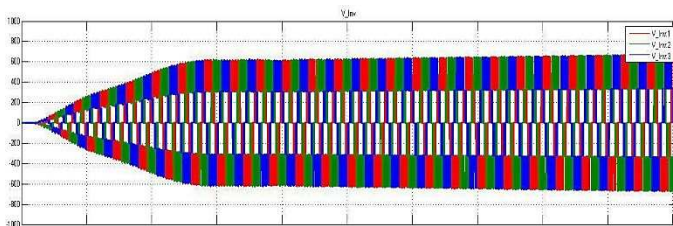


Fig 8. Output Voltage of Inverter

D. Speed Response

In order to evaluate the speed response to change in reference values the reference speed was from 1500 to 1300 RPM at 1 second in the simulation. From the fig 9. It can be clearly seen that the response time required for change in speed is around 0.5 seconds.

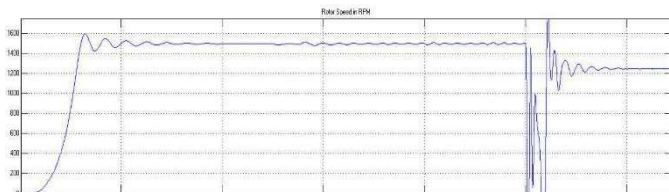


Fig 9. Speed Response of Induction motor

VII. CONCLUSION

The simulation results prove that the proposed approach give a good response on the torque and stator flux. The Speed response of the induction motor which is resulted by the cyclic sector changes of stator flux vector and produces sharp edges is now eliminated. Despite electromagnetic torque is regulated by all structures, it has improved speed response. It can also be seen the improvement in motor acceleration and the change in motor's torque using DTC-SVM compared to classic DTC. More over from chart 1, the THD values of output of inverter have been reduced considerably even though Solar PV module is being used as the source along with several stages of DC voltage regulation.

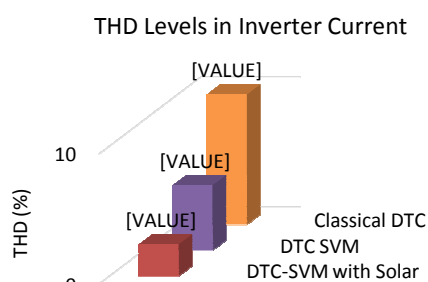


Chart 1. Comparison of THD Levels

VIII. FUTURE SCOPE

This paper can be developed in the future to meet the very essential requirement of efficient way of water pumping in very remote rural areas where there is no supply of electric utility grid. Since this simulation prototype modeled using data

acquired from a commercially available solar PV module, the implementation of this system for rural solar water pumping application could be a great boon of relief for the farmers. This entire project is designed such that the amount of power required for the conventional three phase induction motor during the time of starting has been very well reduced and this will mean in other words that amount of Solar PV modules that need to installed is low, thus cutting down the cost of initial investment to a great extent.

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