Implementation Zeta Converter with Solar PV Array using BLDC Motor for the application Water Pumping

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Abstract— This paper proposes a solar photovoltaic (SPV) array fed water pumping system utilizing a zeta converter as an intermediate DC-DC converter in order to extract the maximum available power from the SPV array. Controlling the zeta converter in an intelligent manner through the incremental conductance maximum power point tracking (INC-MPPT) algorithm offers the soft starting of the brushless DC (BLDC) motor employed to drive a centrifugal water pump coupled to its shaft. Soft starting i.e. the reduced current starting inhibits the harmful effect of the high starting current on the windings of the BLDC motor. A fundamental frequency switching of the voltage source inverter (VSI) is accomplished by the electronic commutation of the BLDC motor, thereby avoiding the VSI losses occurred owing to the high frequency switching. A new design approach for the low valued DC link capacitor of VSI is proposed. The proposed water pumping system is designed and modeled such that the performance is not affected even under the dynamic conditions. Suitability of the proposed system under dynamic conditions is demonstrated by the simulation results using MATLAB/Simulink software.

Keywords— SPV array, Zeta converter, INC-MPPT, BLDC motor, Electronic commutation..

I. INTRODUCTION

Power electronics is the application of solid-state electronics for the control and conversion of electric power. It also refers to a subject of research in electronic and electrical engineering which deals with design, control, computation and integration of nonlinear, time varying energy processing electronic systems with fast dynamics.

The first high power electronic devices were mercury-arc valves. In modern systems the conversion is performed with semiconductor switching devices such as diodes,thyristors and transistors, pioneered by R. D. Middlebrook and others beginning in the 1950s. In contrast to electronic systems concerned with transmission and processing of signals and data, in power electronics substantial amounts of electrical energy are processed. An AC/DC converter (rectifier) is the most typical power electronics device found in many consumer electronic devices, e.g. television sets, personal computers, battery chargers, etc. The power range is typically from tens of watts to several hundred watts. In industry a common application is the variable speed drive (VSD) that is used to control an induction motor. The power range of VSDs start from a few hundred watts and end at tens of megawatts.

The power conversion systems can be classified according to the type of the input and output power

- AC to DC (rectifier)
- DC to AC (inverter)
- DC to DC (DC-to-DC converter)
- AC to AC (AC-to-AC converter)

2 MATRIX CONVERTERS AND CYCLOCONVERTERS

Cycloconverters are widely used in industry for ac to ac conversion, because they are able to be used in high-power applications. They are commutated direct frequency converters that are synchronised by a supply line. The cycloconverters output voltage waveforms have complex harmonics with the higher order harmonics being filtered by the machine inductance. Causing the machine current to have fewer harmonics, while the remaining harmonics causes losses and torque pulsations. Note that in a cycloconverter, unlike other converters, there are no inductors or capacitors, i.e. no storage devices. For this reason, the instantaneous input power and the output power are equal.[13]

II. LITERATURE SURVEY

2.1 DC link converters:

DC Link Converters, also referred to as AC/DC/AC converters, convert an AC input to an AC output with the use of a DC link in the middle. Meaning that the power in the converter is converted to DC from AC with the use of a rectifier, and then it is converted back to AC from DC with the use of an inverter. The end result is an output with a lower voltage and variable (higher or lower) frequency.[12] Due to their wide area of application, the AC/DC/AC converters are the most common contemporary solution. Other advantages to AC/DC/AC converters is that they are stable in overload and no-load conditions, as well as they can be disengaged from a load without damage.[15]

1.2 HYBRID MATRIX CONVERTER:

Hybrid matrix converters are relatively new for AC/AC converters. These converters combine the AC/DC/AC design with the matrix converter design. Multiple types of hybrid converters have been developed in this new category, an example being a converter that uses uni-directional switches and two converter stages without the dc-link; without the capacitors or inductors needed for a dc-link, the weight and size of the converter is reduced. Two sub-categories exist from the hybrid converters, named hybrid direct matrix converter (HDMC) and hybrid indirect matrix converter (HIMC). HDMC convert the voltage and current in one stage, while the HIMC utilizes separate stages, like the AC/DC/AC converter, but without the use of an intermediate storage element.[16][17]

1.3 Applications:

Below is a list of common applications that each converter is used in.

AC Voltage Controller: Lighting Control; Domestic and Industrial Heating; Speed Control of Fan, Pump or Hoist Drives, Soft Starting of Induction Motors, Static AC Switches [10](Temperature Control, Transformer Tap Changing, etc.)

1.4 Simulations of power electronic systems

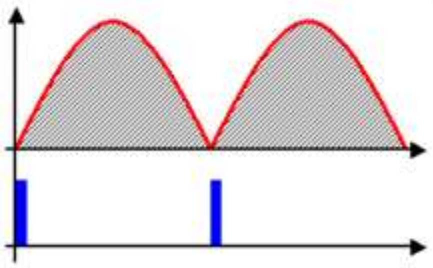


Fig 1.11:Output voltage of a full-wave rectifier with controlled thyristors

Power electronic circuits are simulated using computer simulation programs such as PSIM andMATLAB/simulink. Circuits are simulated before they are produced to test how the circuits respond under certain conditions. Also, creating a simulation is both cheaper and faster than creating a prototype to use for testing.[18]

1.9 Grid voltage regulation

Power electronics can be used to help utilities adapt to the rapid increase in distributed residential/commercial solar power generation. Germany and parts of Hawaii, California and New Jersey require costly studies to be conducted before approving new solar installations. Relatively small-scale ground- or pole-mounted devices create the potential for a distributed control infrastructure to monitor and manage the flow of power. Traditional electromechanical systems, such as capacitor banks or voltage regulators at substations, can take minutes to adjust voltage and can be distant from the solar installations where the problems originate. If voltage on a neighborhood circuit goes too high, it can endanger utility crews and cause damage to both utility and customer equipment. Further, a grid fault causes photovoltaic generators to shut down immediately, spiking demand for grid power. Smart grid-based regulators are more controllable than far more numerous consumer devices.[25]

In another approach, a group of 16 western utilities called the Western Electric Industry Leaders called for mandatory use of "smart inverters". These devices convert DC to household AC and can also help with power quality. Such devices could eliminate the need for expensive utility equipment upgrades at a much lower total cost.[25]

1.5 BRUSHLESS DC MOTORS

Conventional dc motors are highly efficient and their characteristics make them suitable for use as servomotors. However, their only drawback is that they need a commutator and brushes which are subject to wear and require maintenance. When the functions of commutator and brushes were implemented by solid-state switches, maintenance-free motors were realised. These motors are now known as brushless dc motors.

In this chapter, the basic structures, drive circuits, fundamental principles, steady state characteristics, and applications of brushless dc motors will be discussed.

4.2 Structures and Drive Circuits

2.1 Basic structures

The construction of modern brushless motors is very similar to the ac motor, known as the permanent magnet synchronous motor. Fig.1 illustrates the structure of a typical three-phase brushless dc motor. The stator windings are similar to those in a polyphase ac motor, and the rotor is composed of one or more permanent magnets. Brushless dc motors are different from ac synchronous motors in that the former incorporates some means to detect the rotor position (or magnetic poles) to produce signals to control the electronic switches as shown in Fig.2. The most common position/pole sensor is the Hall element, but some motors use optical sensors.

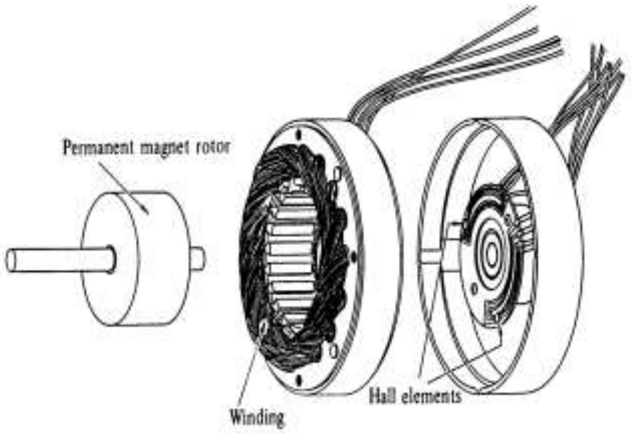


Fig.1.1 Disassembled view of a brushless dc motor

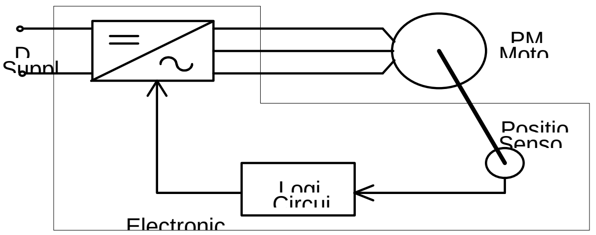


Fig1.2 Brushless dc motor = Permanent magnet ac motor + Electronic commutator

Decreasing the Power Factor:

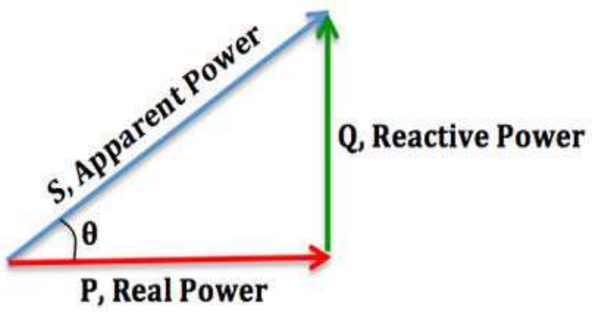


Fig 1.4 Decreasing power factor

As the power factor decreases, the ratio of real power to apparent power also decreases, as the angle θ increases and reactive power increases.

2.2 Lagging and Leading Power Factors:

In addition, there is also a difference between a lagging and leading power factor. A lagging power factor signifies that the load is inductive, as the load will "consume" reactive power, and therefore the reactive component Q is positive as reactive power travels through the circuit and is "consumed" by the inductive load. A leading power factor signifies that the load is capacitive, as the load "supplies" reactive power, and therefore the reactive component Q is negative as reactive power is being supplied to the circuit.

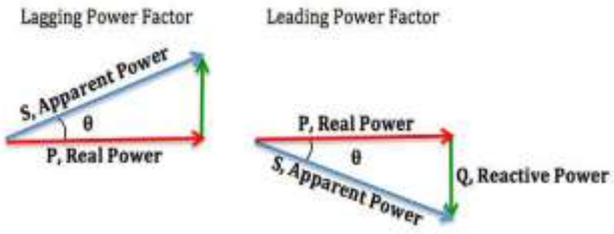


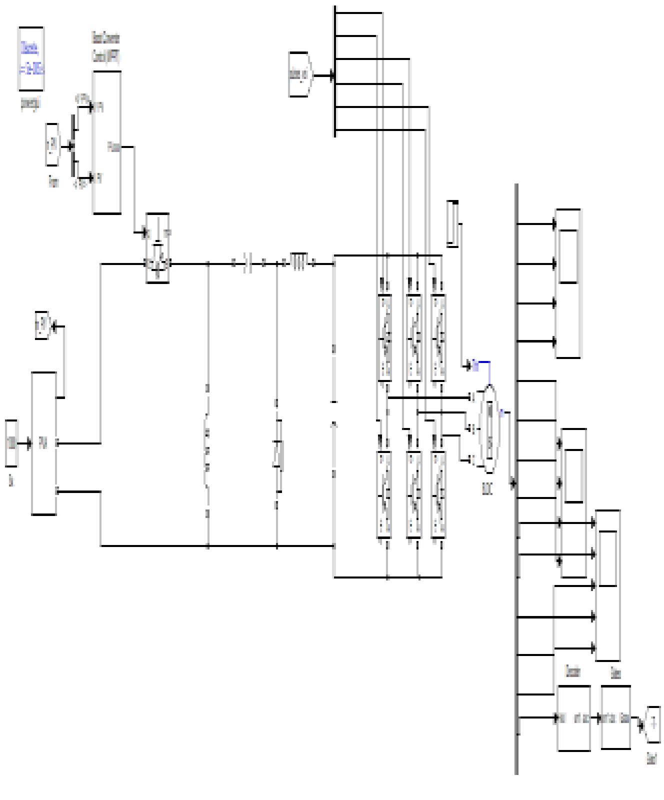
Fig 1.3 Lagging power factor fig 6.7 Leading power factor

If θ is the phase angle between the current and voltage, then the power factor is equal to the cosine of the angle, $\cos\theta$:

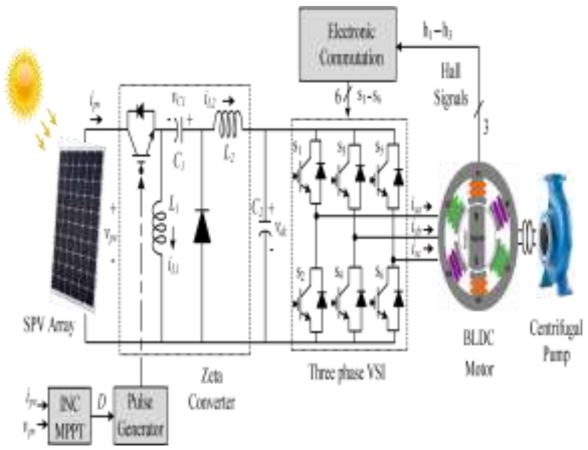
$$|P| = |S| \cos\theta$$

Since the units are consistent, the power factor is by definition a dimensionless number between −1 and 1. When power factor is equal to 0, the energy flow is entirely reactive and stored energy in the load returns to the source on each cycle. When the power factor is 1, all the energy supplied by the source is consumed by the load. Power factors are usually stated as "leading" or "lagging" to show the sign of the phase angle. Capacitive loads are leading (current leads voltage), and inductive loads are lagging (current lags voltage).

3.1 SIMULATION CIRCUIT AND PRPOSED SYSTEMSIMULATION CIRCUIT

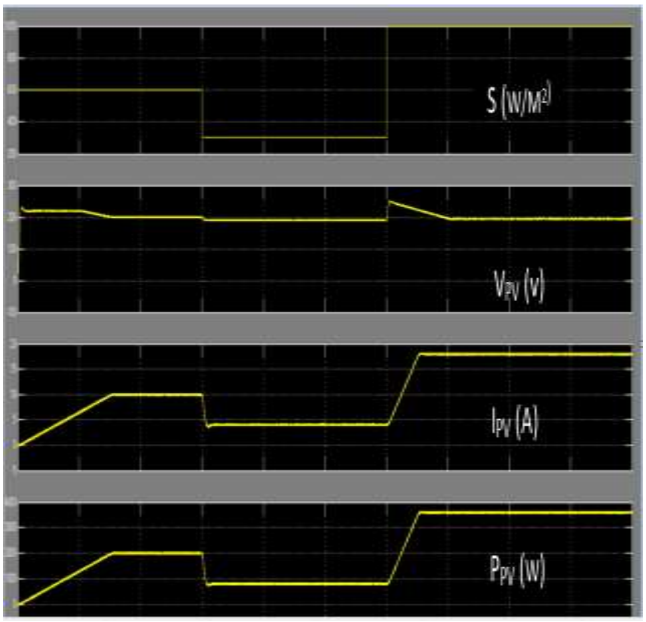


3.2 PROPOSED SYSTEM

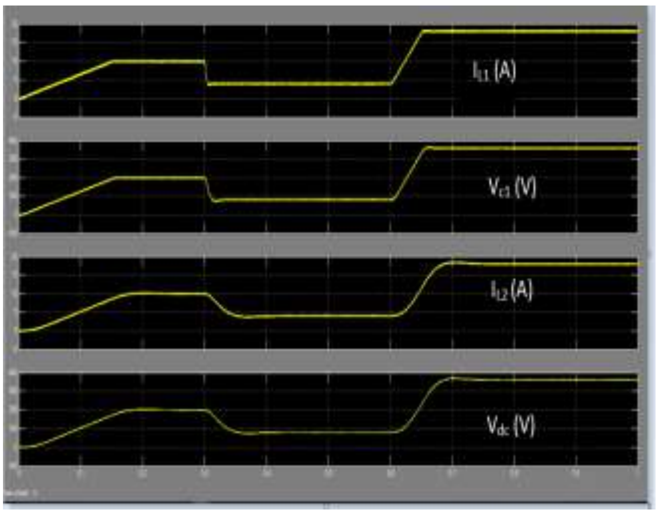


3.4 SIMULINK RESULTS

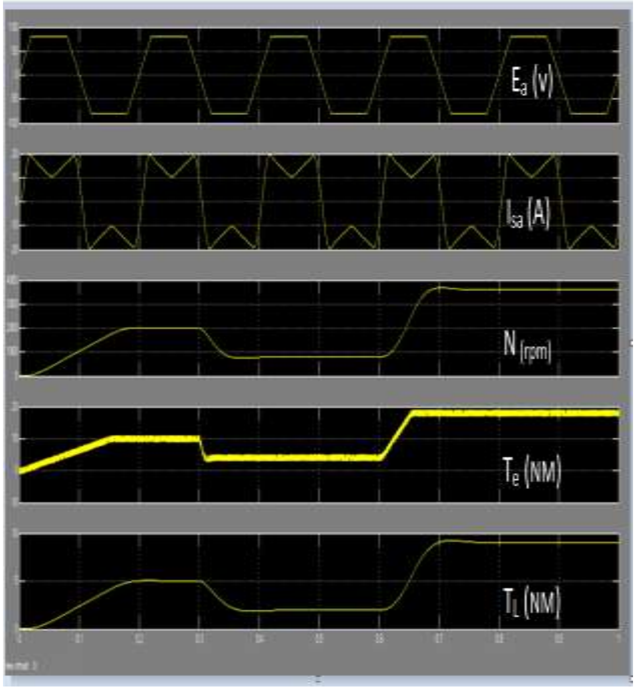
8.1SPV ARRAY VARIABLES



8.2 ZETA CONVERTER VARIABLES



3.3 BLDC MOTOR-PUMP VARIABLES



CONCLUSION

The SPV array-zeta converter fed VSI-BLDC motor-pump for water pumping has been proposed and its suitability has been demonstrated by simulated results using MATLAB/Simulink and its sim-power-system toolbox. First, the proposed system has been designed logically to fulfil the various desired objectives and then modelled and simulated to examine the various performances under starting, dynamic and steady state conditions. The performance evaluation has justified the combination of zeta converter and BLDC motor drive for SPV array based water pumping. The system under study availed the various desired functions such as MPP extraction of the SPV array, soft starting of the BLDC motor, Sstress on IGBT switch and the components of zeta converter by operating it in continuous conduction mode and stable operation. Moreover, the proposed system has operated successfully even under the minimum solar irradiance.

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