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Integration of Hybrid AC/DC Energy Resources Using Versatile Matrix Converter

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***Abstract* – The aim of this paper is to integrate a two different hybrid AC/DC renewable energy sources using versatile matrix converter (VMC). Solar and wind sources are taken for integration to produce the power. VMC is designed using nine switch voltage source converter (NVSC) and current source inverter (CSI). It operates like boost mode and it is developed from the matrix converter. It produces a six input terminals, three for AC sources and other three for DC sources. Modulation technique implemented in this paper is a space vector pulse width modulation. A simulation model for the integration of hybrid AC/DC energy sources developed using MATLAB/Simulink.**

Keywords* – *versatile matrix converter (VMC), nine switch voltage source converter (NVSC), current source inverter (CSI), space vector pulse width modulation (SVPWM).

I. INTRODUCTION

In recent years, environmental concerns are keeping growing and restrictive guidelines has constrain in the use of pollutant sources [2]. Many alternative energy sources like PV, wind, fuel cell, diesel system, gas turbine and micro turbine are used to build a different hybrid energy system. Wind and solar power considered as practical options for future electricity generation. PV systems are generating clean power in a whole host of applications in remote villages in developing countries. For cost-effective concerns it applies in traffic signals, street lights, small garden lights, highway signs, warning signs, lighting for businesses and homes [4]. Practically any renewable source can be integrated with PV. The sun is a direct source of energy. It is a cheaper energy source obtained from nature. Using modern technologies, we can convert solar energy into electricity [3].

Wind energy is the form of solar energy**.** Wind forms due to the uneven heating of air by the sun, irregularity of the earth's surface and rotation of the earth. Wind flow patterns changed due to the earth's landscape, water bodies and vegetative cover. This wind flow or motion energy uses modern wind turbines and it produces electricity [5].

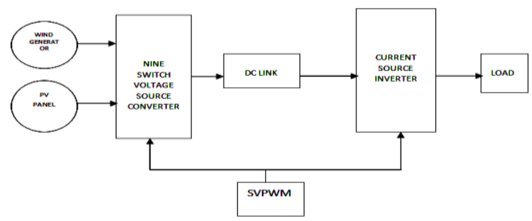

Fig.1. Overview diagram of solar and wind energy.

Wind power produces, when the conversion of wind energy takes place into a useful form of energy. Wind turbines are used to make electrical power, windmills are used for mechanical power and wind pumps are used for water pumping or drainage.

For integration of hybrid energy sources voltage source converters are used. It operating in the specified vector control strategy does perform independent control of active/reactive power at both ends .The ability of voltage source converter makes it suitable for connection to the weak AC networks.

Modulation technique implemented in this project is a space vector modulation (SVM). It is an algorithm for the control of pulse width modulation (PWM). It is a best technique for generating a basic sine wave and it provides a higher voltage to the inverter. It is used for the creation of alternating current (AC) waveforms. Most commonly it uses 3 phase AC powered motors at varying speeds from DC using multiple class D amplifiers [8].

II.PRINCIPLE OF OPERATION

The proposed system consists of a three-phase solar generation systems derived by merging the functionality of some switches found in converters. Depend upon the labeling convention adopted in the converter and the gating signals of the middle joint switches it combine variable sources. Switching states can be written as the XOR-in of

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signals for SA and Sa with the signals to the remaining upper and lower switches kept unchanged. The resulting system uses only nine switches instead of twelve with the upper three and middle three switches to form the DC-AC inverter. The same middle three and lower three switches forms DC-DC converters with a common ground for processing energy flowing from the indicated solar array and battery [6].

In this voltage source converter it consists of six input terminals. They are always divided into two sets for handling either two AC three-phase outputs or a single AC input/output. The switching constrain for this proposed topology is slightly difficult and the middle switches shared by both top and bottom switches. In the nine switch topology the converter input and output voltages can be independently controlled. The middle switch in each leg is shares the inverter and converter. The proposed converter has only three valid switching states per phase.

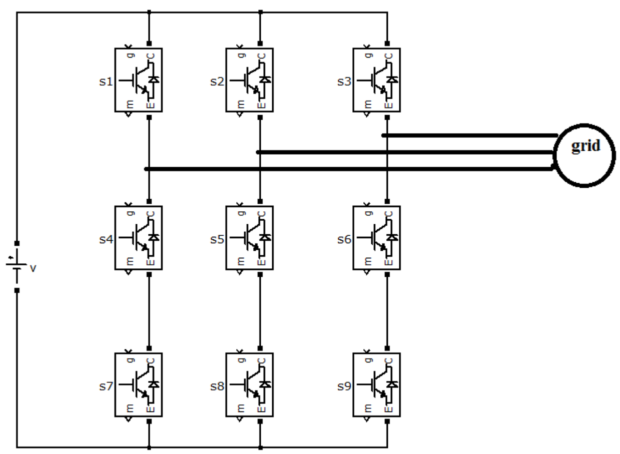

Fig.2. NVSC Circuit Diagram for single leg

In this application multilevel converter has the advantage that they allow harmonic filtering equipment to be reduced or eliminated altogether. By the way of comparison, AC harmonic filters of typical line-commutated converter stations cover nearly half of the converter station area.

Current source inverter converts sinusoidal AC waveforms, magnitude, frequency, and phase into DC waveforms and control it. CSI has high changes in current overtime, so capacitors are normally working on the AC side, while inductors are usually working on the DC side. Due to the absence of freewheeling diodes, the power circuit is compact in size and weight and it tends to be more reliable than voltage source inverter. Although single-phase topologies are possible when compared to the three-phase CSI is more practical.

III. MODULATION TECHNIQUES

1. Amplitude modulation, where the voltage applied to the carrier wave is varied over time.
2. Frequency modulation means that frequency of the carrier waveform varies in small but meaningful amounts.
3. Phase modulation, where the natural flow of the alternating current waveform is delays temporarily.

In this paper Space Vector PWM (SVPWM) is used. It is a new technique for generating a fundamental sine wave that provides a higher voltage to the inverter and lower total harmonic distortion [8].

The reference vector is represented in a αβ-“plane”. This is a two-dimensional plane transformed from a three-dimensional plane containing the vectors of the three phases. The switches being ON or OFF are determined by the location of the reference vector on this αβ-plane.

The lower switches are complementary to the upper switches and only possible combinations switching states are 000, 001, 010, 011, 100, 110, 110 and 111. This means that there are 8 possible switching states for which two of them are zero switching states and six of them are active switching states. These are represented by active (V1-V6) and zero (V0) vectors. The zero vectors are placed in the axis origin.

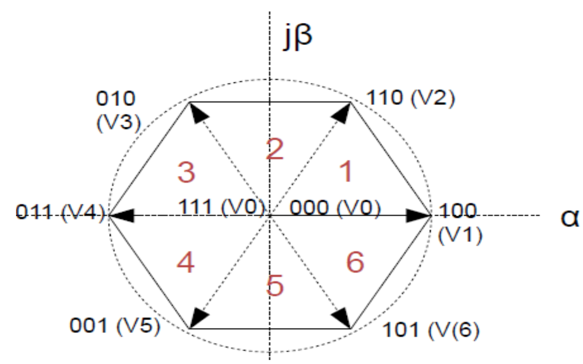

Fig. 3 Space voltage vectors in different sectors

The three-phase system voltage is expressed as

$$V_{a0}+V_{b0}+V_{c0}=0 \quad (1)$$

Instantaneous phase voltages are written as

$$V_a = V\sin(\theta t) \quad (2)$$

$$V_b = V\sin\left(\theta t + \frac{2\pi}{3}\right) \quad (3)$$

$$V_c = V\sin\left(\theta t + \frac{4\pi}{3}\right) \quad (4)$$

When the three-phase voltages are applied to an AC machine it creates a rotating flux. This flux can be denoted as one rotating voltage vector.

The magnitude and angle of this vector is calculated using Clark's Transformation as shown below.

$$V_{ref} = V_\alpha + jV_\beta = \frac{2}{3}(V_a + aV_b + a^2V_c) \quad (5)$$

$$a = e^{\frac{j2\pi}{3}} \quad (6)$$

The angle and magnitude of the reference vector is

$$|V_{ref}| = \sqrt{V_\alpha^2 + V_\beta^2} \quad (7)$$

$$\theta = \tan^{-1}\left(\frac{V_\beta}{V_\alpha}\right) \quad (8)$$

The reference voltage is written as

$$V_\alpha + jV_\beta = \frac{2}{3}\left(V_a + e^{\frac{j2\pi}{3}}V_b + e^{\frac{-j2\pi}{3}}V_c\right) \quad (9)$$

The voltage vectors on the alpha and beta axis is described as

$$\begin{pmatrix} V_\alpha \\ V_\beta \end{pmatrix} = \frac{2}{3}\begin{pmatrix} 1 & \cos\left(\frac{2\pi}{3}\right) & \cos\left(\frac{2\pi}{3}\right) \\ 0 & \sin\left(\frac{2\pi}{3}\right) & -\sin\left(\frac{2\pi}{3}\right) \end{pmatrix} * \begin{pmatrix} V_a \\ V_b \\ V_c \end{pmatrix} \quad (10)$$

$$V_\alpha = \frac{2}{3}\left(V_a - \frac{1}{2}V_b - \frac{1}{2}V_c\right) \quad (11)$$

$$V_\beta = \frac{2}{3}\left(\frac{\sqrt{3}}{2}V_b - \frac{\sqrt{3}}{2}V_c\right) \quad (12)$$

First step is to calculate V_α, V_β and V_{ref} .The next step is to calculate the duration time for each vector V_1-V_6.

V_{ref} is found with 2 active and one zero vector. For sector 1 (0 to π/3) V_{ref} is located with V0, V1 and V2.

V_{ref} in terms of the duration time is considered as

$$V_{ref} * T_c = V_1\frac{T_1}{T_c} + V_2\frac{T_2}{T_c} + V_0\frac{T_0}{T_c} \quad (13)$$

$$V_{ref} = V_1T_1 + V_2T_2 + V_0T_0 \quad (14)$$

The position of V_{ref}, V_1, V_2 and V_0 is described with its magnitude and angle

$$V_{ref} = V_{ref}r^{j\theta} \quad (15)$$

$$V_1 = \frac{2}{3}V_{DC} \quad (16)$$

$$V_2 = \frac{2}{3}V_{DC}e^{\frac{j2\pi}{3}} \quad (17)$$

$$V_o = 0 \quad (18)$$

Dividing this in real and imaginary parts simplifies the calculation for each period. Real part is given as

$$T_cV_{ref}\cos\theta = T_1\left(\frac{2}{3}\right)V_{DC} + T_2\left(\frac{1}{3}\right)V_{DC} \quad (19)$$

Imaginary part is

$$T_cV_{ref}\sin\theta = T_2\left(\frac{1}{\sqrt{3}}\right)V_{DC} \quad (20)$$

Choosing n as the number of the sector (n=1, 2, 3, 4, 5, 6) the calculations for the time duration in each sector can be calculated.

For each sector, there are 7 switching states for each cycle. It constantly starts and ends with a null vector. It also means that there is no extra switching state needed for changing the sector. The irregular numbers travel in anti-clockwise in each sector and the even sectors travel clockwise.

Table 1
All switching states and its corresponding voltage vector

Switching state			Corresponding Voltage Vectors		
A	B	C	Vector	Magnitude	Angle
0	0	0	V0	0	0
1	1	1			
1	0	0	V1	$\frac{2}{3}V_{DC}$	0
1	1	0	V2	$\frac{2}{3}V_{DC}$	$\frac{\pi}{3}$
0	1	0	V3	$\frac{2}{3}V_{DC}$	$\frac{2\pi}{3}$
0	1	1	V4	$\frac{2}{3}V_{DC}$	π
0	0	1	V5	$\frac{2}{3}V_{DC}$	$\frac{4\pi}{3}$
1	0	1	V6	$\frac{2}{3}V_{DC}$	$\frac{5\pi}{3}$

For sector 1 it goes through these switching states: 000-100-110-111-110-100-000 one round and then back again. This is during the time T_c and it has to be divided amongst the 7 switching states and three of them being zero vectors are calculated for all the sectors.

$$T_C = T_{0/4}+T_{1/2}+T_{0/2}+T_{2/2}+T_{1/2}+T_{0/4} \quad (21)$$

For following pattern each sector results in an ON/OFF waveform for each sector and phase. Each switch has its switching information depending on where the reference vector is located.

For Sector 1, the switch is ON between T0/4 toTc-T0/4 in the 1st phase between $T_0/4$ and T1/2 to T_c-($T_0/4+T_1/2$) for the second phase and so on. For the switch to know that it is switched ON at these specific times given and a timer that can give this information.

IV.SIMULATION RESULTS OF CONVENTIONAL SYSTEM

In conventional system, three AC sources and three DC sources are connected in the input side. Each phase AC voltage is 58v is given and for DC source 55v is given. Both AC and DC current flows in the NVSC circuit. CSI convert the DC source into an AC source. Pulse Width Modulation (PWM) are applied to the NVSC and Space Vector Pulse Width Modulation (SVPWM) is used in CSI. Pulse width modulation (PWM) is a modulation technique confirms the width of the pulse formally the pulse duration, based on modulator signal information. This modulation is mainly used to allow the control of the power supplied to electrical devices especially to inertial loads such as motors. Result and outputs are analyzed by connecting induction motor at the load side.

A). Design of conventional system

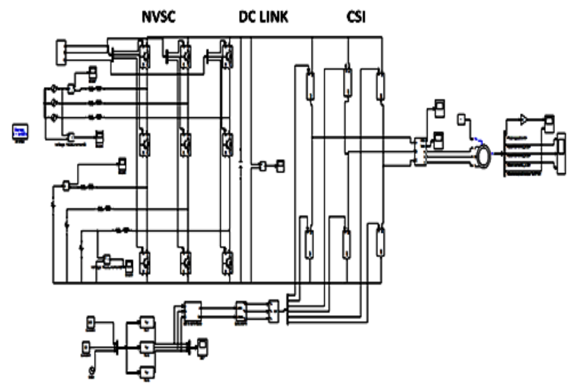

Fig .4.Simulation diagram of conventional system by using MATLAB/ SIMULINK.

B).Input AC voltage

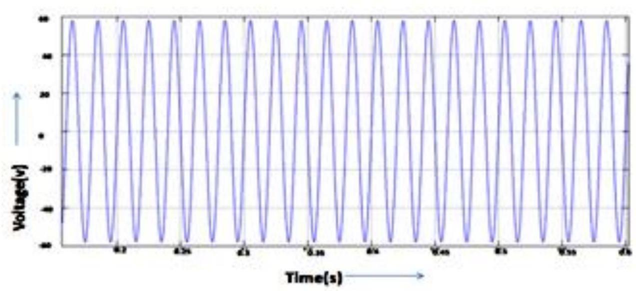

Fig.5.Waveform of input AC voltage

The above waveform shows that the input AC voltage given in each phase.

C).Input DC voltage

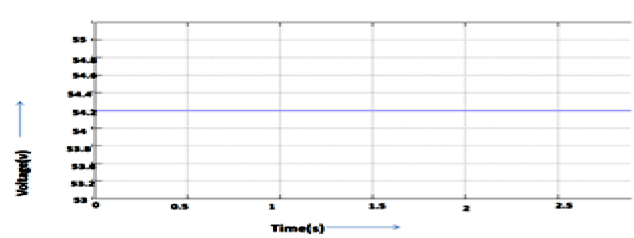

Fig.6. input DC voltage waveform

The above waveform describes the input DC voltage is given to the conventional circuit. It consists of three DC sources in the input side.

D) NVSC output DC voltage

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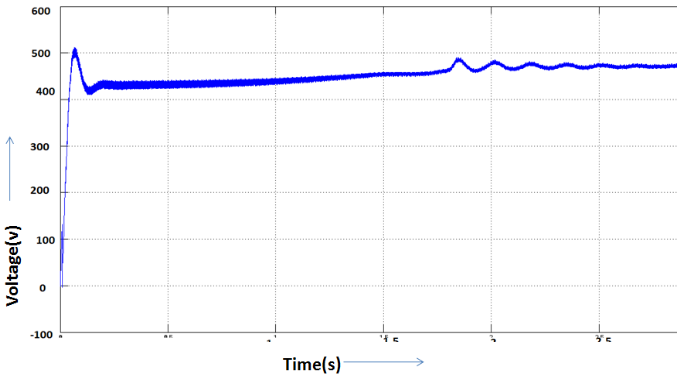

Fig.7. NVSC output voltage

Both AC and DC voltage are integrated in this voltage source converter. The output voltage obtained from this converter is a dc voltage.

E).CSI output voltage

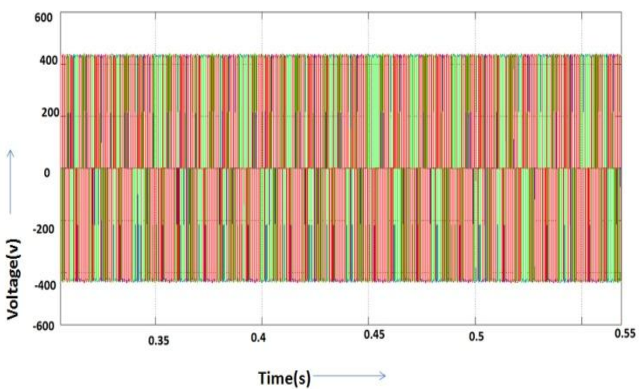

Fig.8.CSI output voltage

CSI convert DC voltage into AC voltage and here AC voltage obtained as 400V.

F). Motor performance

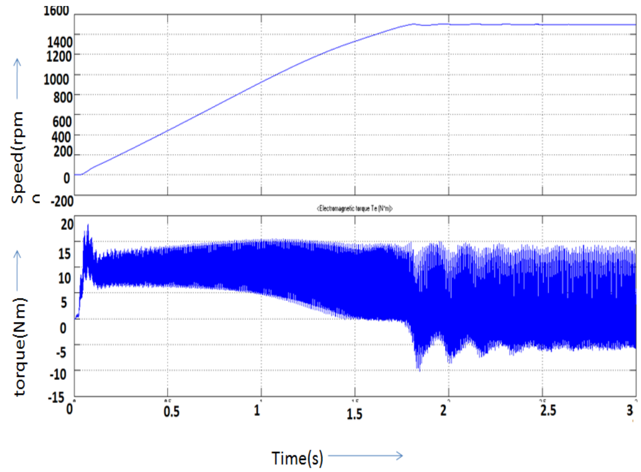

Fig.9. Performance of motor

Waveform gives that the load which is connected to the circuit is three phase induction motor. While the motor speed and torque is taken for the analysis.

V. SIMULATION RESULTS OF PROPOSED SYSTEM

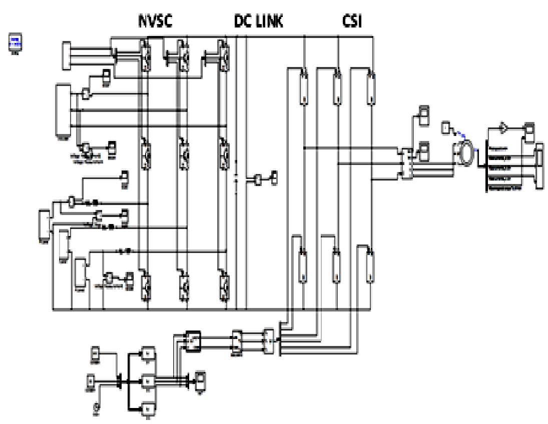

Fig .10. Simulation diagram of proposed system

Solar and wind energy are integrated and corresponding output is taken. In proposed system instead of three AC source wind generator are used to produce the three phase source and instead of three DC sources solar panel are connected in the input side. Both are integrated using nine switch voltage source converter. In each phase AC voltage 58V is given and for DC source 55V is given. Both AC and DC current flows in the NVSC circuit. CSI convert the DC source into AC source.

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Space Vector Pulse Width Modulation (SVPWM) is applied to the NVSC and CSI and its output is analyzed by connecting induction motor at the load side.

G).Wind generator voltage

AC voltage is generated using wind generator. The voltage is produced as 58v in each phase.

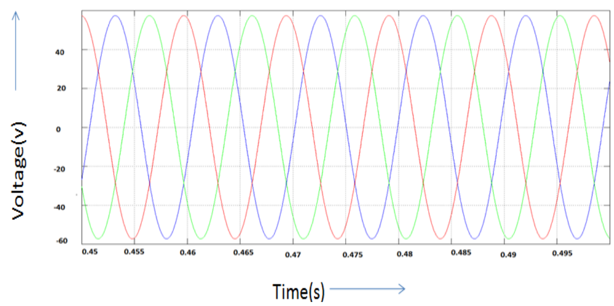

Fig.11.AC voltage generate by wind generator

H).Solar panel DC voltage

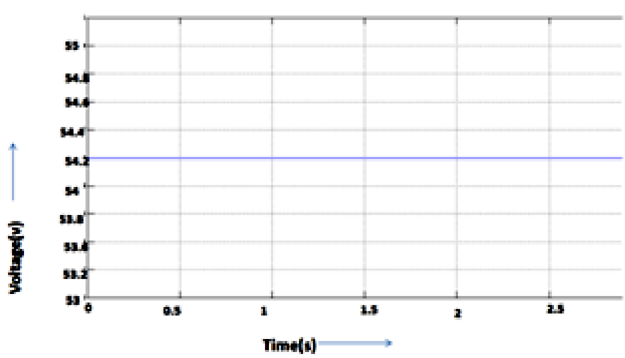

Fig.12.DC voltage generated by PV panel

DC voltage is generated in the proposed system by using PV panel. The voltage generated from the PV panel is 55V.

I).NVSC output DC voltage

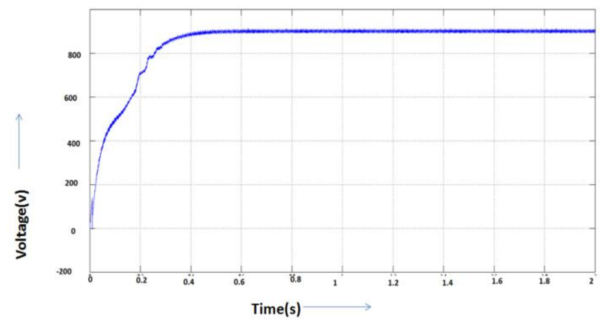

Fig.13. NVSC output voltage waveform

Output voltage of NVSC is 900V. It integrates the wind generator AC voltage 58V in each phase and PV panel DC voltage 55V. It integrates and boosts the voltage and it is given to the CSI.

J). CSI output voltage

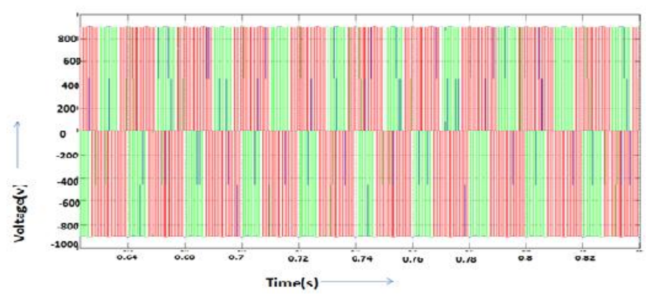

Fig.14.CSI output voltage

The above figure show that CSI output voltage. It converts DC voltage into ac voltage and its value is 840V.

K).Motor performance

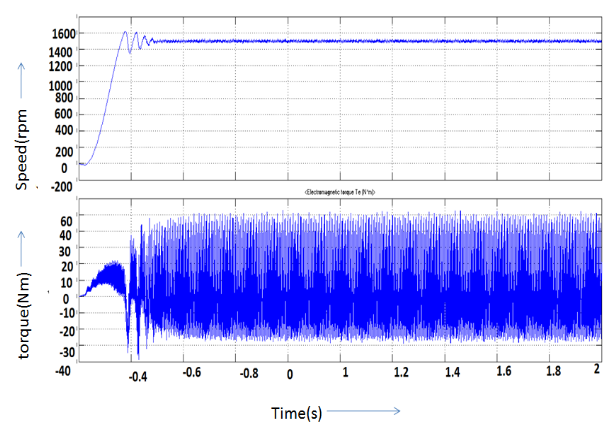

Fig.15.motor performance

The above figure shows that the performance of the motor while it is operated using solar and wind energy sources. Motor speed attained is 1500rpm and torque produced is 40Nm.

Table 2
Comparison of results

Parameters	Existing system	Proposed system
Input AC voltage	58V	58V
Input DC voltage	55V	55V
NVSC output voltage	520V	900V
Current source inverter	400V	840V
Speed of the motor	1500RPM	1500RPM
Torque of the motor	15Nm	40Nm

VI .CONCLUSION

In this project, hybrid two energy sources such as solar and wind energy is to integrate to the grid. Here nine switch voltage source converters are used to obtain the better performance. For control purpose space vector modulation technique (SVPWM) is used .SVPWM are applied in both NVSC and current source inverter (CSI). Simulation results are studied and the simulation results of the same are obtained using MATLAB/SIMULINK platform. The simulation results shown were compared for both existing and proposed system.

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