Design and Implementation of 11-Level Inverter with Facts Capability Using Modular Multi-Level Converter (MMC) Topology

R. Santhosh Kumar[1] C. Arul Kumar[2]
[1,2]Department of Electrical & Electronics Engineering
[1,2]Paavai Engineering College, Namakkal, India

Abstract— *In this paper presents the scheme of a multi-level inverter with SSSC capability for small to mid-size (10kw-20kw) wind placed by using most progressive modular multi-level converter (MMC) topology. The inverter is fixed between the renewable energy source, especially a wind turbine, and the distribution grid in form to fix the power factor of the grid at a target value, anyway of wind speed, by regulating active and reactive power required by the grid. This paper learning, a SSSC is used to realize the effect of this device in controlling active and reactive power. The proposed multilevel inverters due to compact harmonic distortion, lower electromagnetic interference, and developed dc link voltages. Though, it has some disadvantages such as established number of modules, complex pulse width modulation control technique, and voltage-balancing problems. In a novel topology with a reversing-voltage module is proposed to develop the multilevel performance by compensating the disadvantages mentioned. Thus, the total cost and complexity are significantly reduced particularly for higher output voltage levels. Results show that the reduced-scale 11-level inverter is able to fix PF of the grid as well as being companionable with IEEE standards. Finally, a model of the 11-level proposed topology is complete and tested to display the performance of the inverter by investigational results.*

Keywords— Modular Multi-Level Converter (MMC), Static Synchronous Series Compensator (SSSC), Power Factor (PF).Harmonic Distortion, Real and Reactive Power

I. INTRODUCTION

Fundamentally Inverter is an arrangement that converts DC power to AC power at desired output voltage and frequency. Drawbacks of inverter are less efficiency, high THD, and high switching losses. To overcome these drawbacks, we are going to use multilevel inverter. The duration Multilevel instigated with the three-level converter. The conception of multilevel converters has been announced since 1975. The cascade multilevel inverter was first suggested in 1975, in recent years multilevel inverters are used for high voltage and high power applications [1]. Modular multilevel converters have abundant potential in high power applications, such as dc interconnections, Off-shore, and Dc power grids wind power generation are in must of exact power flow control and high efficiency power conversion in order to reduce both their environmental impact and their operating costs [2]. A rectifier well-found with a maximum power point tracker (MPPT), converts the output power of the wind turbine to a dc power. The dc power is then converted to the preferred ac power for power lines using an inverter and transformer modern growths in wind energy, utilizing smoother wind energy inverters (WEIs) has become an important issue. There are allocations of single-phase lines in the United States, which power small farms or remote houses [3], [4].

Multilevel converters are used for triumphing medium voltage power conversion without transformers. Two of the representatives are: 1) Diode-clamped multilevel converter (DCMC); 2) the flying-capacitor multilevel converter (FCMC). The three-level DCMC or NPC converter has been put into practical use. If a voltage-level number is more than three in the DCMC, inherent voltage difference occurs in the series-connected Dc Capacitors, thus resulting in needing an exterior balancing circuit (such as a buck–boost chopper) for a couples of Dc capacitors [5]. Converters for these applications are commercially offered by a mounting group of companies in the field [6]. This discovers the static synchronous series compensator (SSSC) FACTS controller act in terms of stability improvements. A Static Synchronous Series Compensator (SSSC) is a member of FACTS family which is coupled in series with a power system. It consists of a solid state voltage source converter (VSC) which generates a controllable alternating current voltage at essential frequency. When the injected voltage is kept in quadrature with the line current, it can emulate as inductive or capacitive reactance so as to influence the power flow through the transmission line [7], [8].The switching power converter-based FACTS controllers can carry this out. Among the different alternatives of FACTS devices, Static Synchronous Series Compensator (SSSC) is proposed as the most suitable for the present application. The main function of the SSSC is to dynamically control the power flow over the transmission line [9]. At the same time, rising costs and growing environmental concerns make the process of building new power transmission and distribution lines increasingly complicated and time consuming. The switching power converter-based FACTS controllers can carry this out. Among the different variants of FACTS devices, Static Synchronous Series Compensator (SSSC) is proposed as the most adequate for the present application. The DC inner bus of the SSSC allows incorporating a substantial amount of energy storage in order to enlarge the degrees of freedom of the SSSC device and also to exchange active and reactive power with the utility grid. The applications of the SSSC are 1) To control the power flow, 2) To increase the power transfer limits, 3) To improve the transient stability 4) to damp out power system oscillations 5) to mitigate Sub Synchronous Resonance (SSR) [11].

In this paper, the proposed WEI employs MMC topology, which has been introduced recently for FACTS applications. Replacing conventional inverters with this inverter will eliminate the need to use a separate capacitor bank to fix the PF of the local distribution grids. Clearly, depending on the size of the power system, multiple inverters might be used in order to reach the desired PF. The unique work in this paper is the use of MMC topology for a single phase voltage-source inverter, which meets the IEEE standard 519 requirements, and is able to control the PF of the grid regardless of the complete grid-connected mode configuration of the proposed inverter. The dc link of the inverter is connected to the wind turbine through a rectifier using Dc-Dc converter & MPPT and its output terminal is connected to the utility grid through a series-connected second-order filter and a distribution transformer [10].

II. MODULAR MULTILEVEL INVERTER

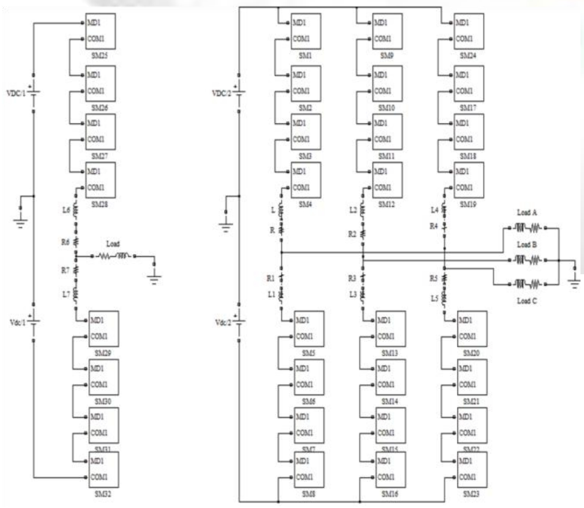
Fig. 1(a) and 1(b) shows the single phase and three phase equivalent circuit of 11-level MMC configuration, the two non-coupled buffer inductors are inserted into the arms, since they do not disturb operation or generate overvoltage for the semiconductors. The buffer inductor can limit the AC-current, whenever the DC-Bus is short circuited (fault condition) and it act as passive filter during normal condition [13], [14]. The DC Link of MMC is connected to high-voltage sources depending on the working purpose of the converter. The output of the converter is the connection point of the upper and lower arm which is connected to RL load. The Main applications: Field for high power converters is mainly centered on high power machine drives and power converters grid applications such as HVDC, FACTS [20]. Classification of MMC: 1.Single Phase Bridge Cells (SPBC) 2. Single Delta Bridge Cells (SDBC) 3. Double-Star Chopper Cells (DSCC) 4. Double-Star Bridge Cells (DSBC).

In the basic configuration of modular multilevel converter (MMC), The converter has one leg comprises of two arms including the upper arm and the lower arm, with each arm having four Sub-Modules (SM) and two non-coupled buffer inductors and an equivalent resistor [12]-[15].

The goal of the arm inductors is twofold:

- They are necessary in order to handle the voltage difference between the top and bottom side of the converter. This feature allows them to be used for current control purposes.
- They limit the current in case of fault (Short circuit).

The basic operating principle of this kind of converter uses the differential voltage between the DC side (Vdc) and the overall DC component of the output voltage at the cells.



(a) (b)

Fig. 1: (a) Single phase equivalent circuit of modular multi-level inverter. (b) Three phase equivalent circuit of modular multi-level inverter.

This produces a circulating current (i_{circu}), which is responsible for the limb power transfer between both sides of the converter. The differential control strategies could be used for this purpose. The instantaneous power at each cell will have oscillations at frequencies typically multiple of the fundamental frequency. Hence these oscillations will lead to variations in cells capacitors voltage, what is a characteristic feature of this topology. The possible switching combinations for modular multi-level converter are summarized as Table 1. In this table S_{JT} stands for the state (ON=1 OFF=0) of the top switch of j^{th} sub-module and the bottom switch of j^{th} sub-module is in complementary state. Where it connected series to the grid. The SSSC inject a voltage in series to the line, 90 degree phase shifted with load current operating as a controllable series capacitor.

Sub Module	Output Voltage (Vun)					
	Vdc /2	-Vdc/2	0V			
S1T	0	1	0	1	0	1
S2T	0	1	1	0	1	0
S3T	1	0	1	0	0	1
S4T	1	0	0	1	1	0
Inserted cells(N)	2	2	2	2	2	2

Table 1: Switching Combinations for Modular Multi- Level Converter

SSSC-output voltage lags behind the line current by 90 degree to provide effective series compensation. In addition SSSC can be gated to produce an output voltage that leads the line current by 90 degree, which provides additional inductive reactance in the line.

III. PROPOSED CONTROL STRATEGY

In the proposing method consists of a PV panel with DCDC converter, MPPT algorithm, Rectifier, multi-level inverter, SSSC controller and Ac load. The block diagram of proposing system shown in fig 3.1. When the sunlight falls on the PV panel the photon in the sunlight is used for converting of light energy into the direct current. The direct current is fed into the DC-DC converter. Coupling Transformer used to connect the SSSC For feeder lines. It operates a switch mode 0=off 1=on conditions open and close the circuit.

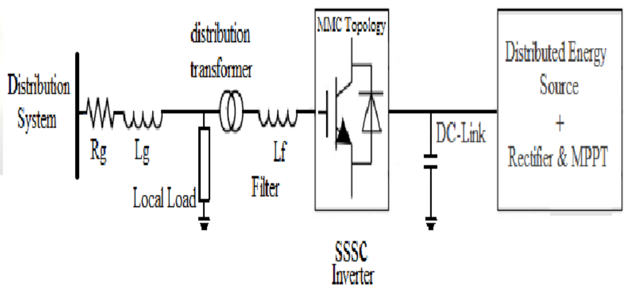


Fig. 2: Circuit diagram of proposed control strategy

DC-DC Converter can be used as switching mode regulators to convert an unregulated DC voltage to a regulated DC output voltage. The MPPT (Maximum Power Point Tracking) is a fully electronic system; it varies the module's operating point, so that the modules will be able to deliver maximum available power. As the outputs of PV systems are dependent on the temperature, irradiation, and the load characteristic MPPT cannot deliver the output voltage perfectly. The filter is any circuit that will remove some parts of a signal or power source, while allowing other parts to continue on without significant hindrance. In a power supply, the filter must remove or drastically reduce the Ac variations while still making the desired DC available to the load circuitry. The Multilevel Converter is used for converting DC into AC from Load. The aim of the designed inverter is to transfer active power coming from the wind turbine as well as to provide utilities with distributive control of SSSC and PF correction of feeder lines. The application of the proposed inverter requires active and reactive power to be controlled fully independent, so that if the wind is blowing, the device should be working as a normal inverter plus being able to fix the PF of the local grid at a target PF. Multilevel converters are used for achieving medium-voltage power conversion without transformers.

A. Operating Principle of SSSC:

The SSSC, sometimes called the S3C, is a series-connected synchronous voltage Source that can vary the effective impedance of a transmission line by injecting a voltage containing an appropriate phase angle in relation to the line current [16]. A series capacitor compensates the transmission-line inductance by presenting a lagging quadrature voltage with respect to the transmission-linecurrent [17].

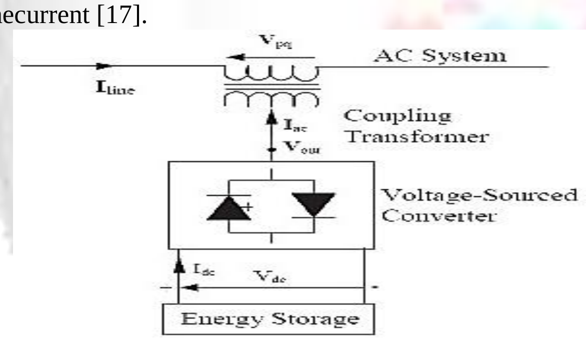


Fig. 3: Static Synchronous Series Compensator

This voltage acts in opposition to the leading quadrature voltage appearing across the transmission-line inductance, which has a net effect of reducing the line inductance. Similar is the operation of an SSSC that also injects a quadrature voltage, *VC* in proportion to the line current but is lagging in phase:

$$Vc = -kXcIc$$

Where VC → the injected compensating voltage

IC → the line current

XC → the series reactance of the transmission

K → the degree of series compensation

1) Modelling of SSSC:

According to the equivalent circuit, suppose Vse=Vse< θ_{se}.The voltage of bus m is taken as the reference vector, $V_m=V_m\angle\theta$. The voltage of bus m is taken as the reference vector $V_m=V_m\angle\theta_m$ [18]. The voltage source, Vse, is the series injected voltage, and it is controllable in both its magnitudes and phase angles and is also the control variable of the SSSC. $V=V_n<\theta_n$ is the voltage at bus n.

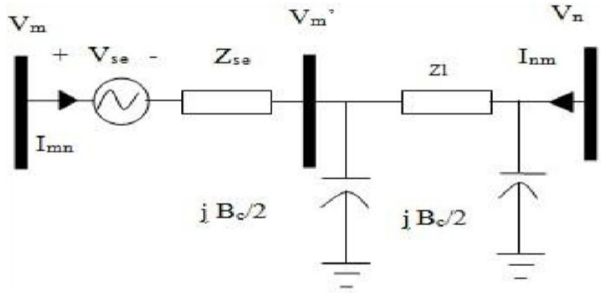


Fig. 4: Equivalent circuit of the embedded SSSC using voltage source

Zse = Rse + j Xse is the impedance of the series couplingtransformer [19]. And $Z_l= R_l + j X_l$ are the charging susceptance and the impedance of the line respectively. FromFig.3.

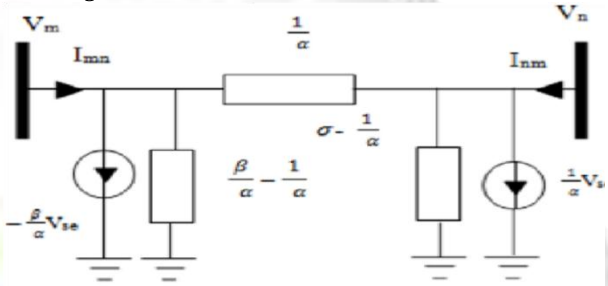


Fig. 5: Representation of the SSSC using current source

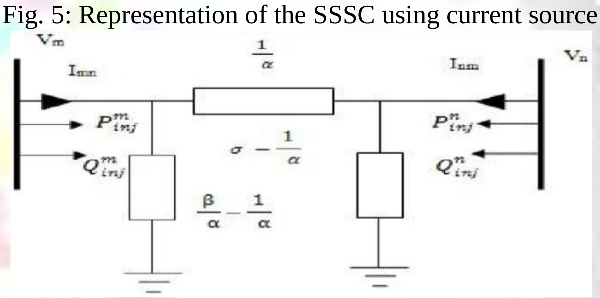


Fig. 6: The power injection π-model of embedded SSSC

$$\alpha = j\,\frac{Bse}{2}\,Z\,se\,Z\,l + Z\,l + Z\,se \qquad (1)$$

$$\beta = \left(1 + j\frac{Bc}{2}\,Z\,l\right) \qquad (2)$$

$$\alpha = Zse\,\beta + Z\,l \qquad (3)$$

From Fig.4, Considering the following vectors:

$$V_{se} = V_{se} \angle \theta_{se}$$

$$V_m = V_m \angle \theta_m$$

$$V_n = V_n \angle \theta_n$$

$$\beta = \beta \angle \theta_\beta$$

From Fig.5 the real and reactive power injections at the sending and receiving bus:

P^m_{inj}, Q_{inj}^m, P_{inj}^n, Q_{inj}^n can be calculated as follows:

$$S^m{}_{inj}{}^* = V^*{}_m\left(-\frac{\beta}{\alpha}\,V\,se\right) = -A\,V_mV_{se} \angle (\theta_{se} - \theta_m + \theta_A)$$

$$\frac{\beta}{\alpha} = A = A\angle\,\theta A \qquad (4)$$

$$P^m{}_{inj} = -AV_mV_{se}\cos(\theta_{se} - \theta_m + \theta_A) \qquad (5)$$

$$Qminj = -AVmVsesin(\theta se - \theta m + \theta A) \qquad (6)$$

$$S^n{}_{inj}{}^* = V^*{}_n\left(-\frac{1}{\alpha}\,V\,se\right) = \frac{A\,V\,n\,V\,se}{\beta}\angle(\theta_{se} - \theta_n + \theta_A - \theta_\beta)$$

$$Pninj = \frac{A\,V\,n\,V\,se}{\beta}\cos(\theta se - \theta n + \theta A - \theta\beta) \qquad (7)$$

$$Q^n{}_{inj} = \frac{A\,V\,n\,V\,se}{\beta}\sin(\theta_{se} - \theta_n + \theta_A - \theta_\beta) \qquad (8)$$

The admittance $Y^u{}_m$ and $Y^u{}_n$ can be written by,

$$Y^u{}_m = \frac{P^umi - jQ^umi}{(V^um)^2} \qquad (9)$$

$$Y^{u}_{n} = \frac{P^{u}ni - jQ^{u}ni}{(V^{u}n)^{2}} \qquad (10)$$

IV. Simulation and Practical Results

In order to verify the modulation method, an 11-level MMC converter is simulated using Matlab/Simulink and its performance is studied for load. The simulation is 20 s long and contains severe ramping and de-ramping of the wind turbine. The goal is to assess the behavior of the control system in the worst conditions.

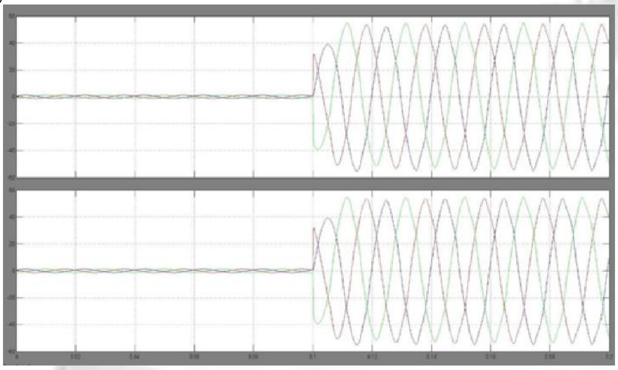


Fig. 7: Source and Load Current Waveforms

Figure.7 shows the source and load current for the modern multilevel converter which is obtained from the solar panel. The variation of current waveform source dynamic load. Source and load current varying depend from SSSC On and off. SSSC off condition current is varying from some oscillations. The voltage obtained from the wind turbine is changed due to the variation in the wind speed. But the variation of current due to dynamic load at 0.1s.

Fig. 8: Source and Load Voltage waveforms without SSSC

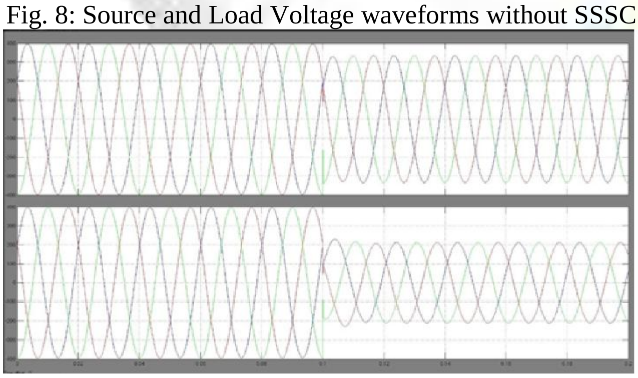


Fig. 9: Source and Load Voltage Waveforms with SSSC

Figure.8 Shows Source and Load Voltage waveforms without and with SSSC. Due to the Dynamic load voltage and current oscillate. This may affect the Power Factor it may stabilize using SSSC. The output voltage is measured using a voltage measurement unit connected across the two wind turbine system and the output voltage is displayed via a scope. Thus Oscillation of line voltage wave form due to the dynamic load. But wave form of the WECS is still not constant without SSSC. This operation SSSC is not operated so voltage sag occurs in wave forms. The output voltage is measured using a voltage measurement unit connected across the load and the output voltage is displayed via a scope. Thus Oscillation of voltage waveform due to the dynamic load stabilizes using SSSC with MMC Topology. That condition SSSC are connected. Here the voltage sags may stabilize before 0.1s using gate pules of SSSC.

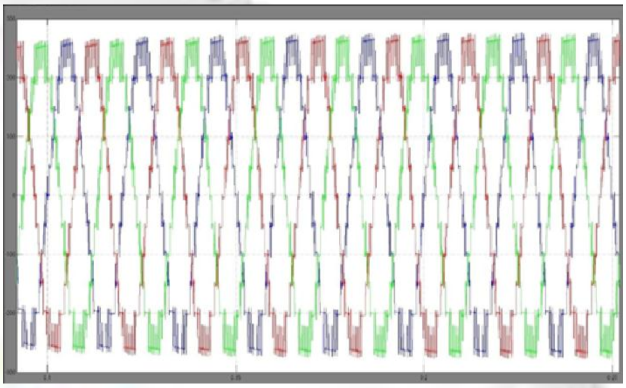


Fig. 10: Output Voltage of 11-Level Inverter

This is the Triggering Pulse obtain using MMC topology. That may apply to SSSC to maintain the PF. PF is set to 0.65 and the target PF is 0.90. In this case, the job of the inverter is to fix the PF at the target PF regardless of the input active power from the wind emulator.PF before compensation is 0.65 and after the compensation is constant at the target PF, which is 0.90 in this case, regardless of the input active power from the wind emulator. The amount of active power which is drawn from the grid changes with the amount of incoming active power from the wind emulator. When the output power of the wind turbine is increased, the level of active power provided by the feeder line is decreased by the same amount. The inverter transfers the whole active power of the wind, excluding its losses, to the grid. The amount of reactive power is dictated by the target PF.

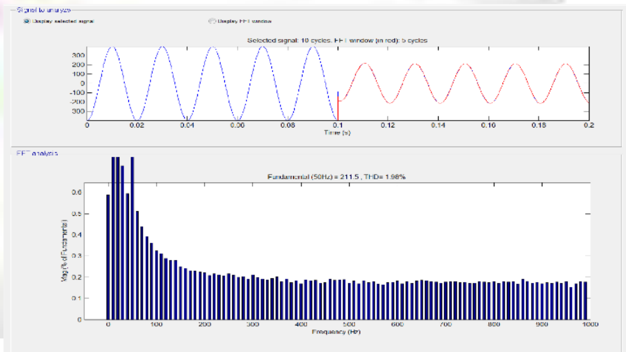


Fig. 11: FFT Analysis for Load voltage waveform without SSSC

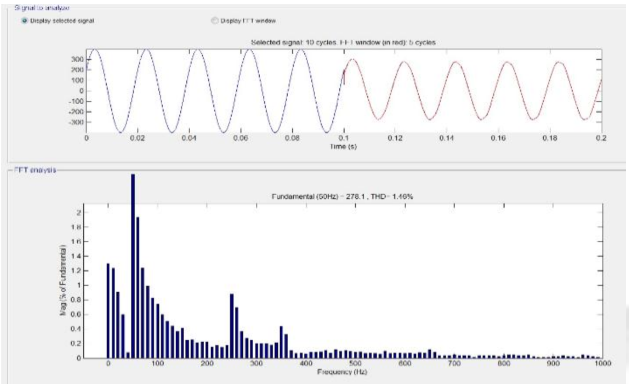


Fig. 12: FFT Analysis for Load voltage waveform with SSSC

The Fourier analysis of this waveform is expressed and the THD of this load voltage at grid by using MMC topology without SSSC is 1.98% and with SSSC is 1.46%, so the best way is to use SSSC controller to minimize total harmonic distortion. Where without SSSC the THD is 1.98%, so we have to reduce 0.52% of THD by proper using of SSSC controller.

V. Conclusion

In this Paper new single-phase MMC built SSSC inverter for grid connection is proposed. The proposed MMC inverter controls the DC link voltage as well as the active and reactive power transmitted between the renewable energy sources, specially wind turbine, and the grid in order to regulate the power factor (PF) of the grid regardless of the input active power from wind turbines. D-STATCOM is being interchanged by SSSC based power quality development in grid connected wind energy generating system having non- linear load, so as to moderate the cost and also to achieve higher precision of the operation. The 11-level SSSC inverter is simulated and the results are presented to validate the operation of the proposed system. In this effort power factor problems such as voltage variations, flickers, harmonics are established due to connection of wind turbine with the grid. Obviously, depending on the size of the compensation, multiple inverters may be desired to reach the appropriate PF. The simulation studies are carried out in the MATLAB/Simulink environment. To validate the simulation results, an experimental configuration of 11-Level SSSC inverter has been built and tested.

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