Proceedings of 30th Indian Engineering Congress, the 21st Century Engineering: The Make in India Pathway, *December 2015*, pp. 191-198

Technology Upgradation with Multi Level Inverter – A Scheme for Life Enhancement of Short Circuit Alternator

Arun Kumar Datta*

Central Power Research Institute, India; arun@cpri.in, akdbpl@gmail.com

Abstract

Short circuit alternator is a specially designed synchronous generator used to supply bulk amount of energy required during testing of electrical power equipment. The alternator discussed here is of 1500MVA rating and can be operable in dual mode i.e. as a motor or as a generator. A static drive based on current source inverter (CSI) is used for motoring operation of this machine. Several phenomena such as high level of harmonics, common mode voltage, shaft voltage, bearing current have been observed in the present system. Eventually all these has a direct or indirect impact on the life of the machine and its journal bearings. A simulation model of the present system and its detailed analysis endorses that the conventional CSI is responsible for those effects. Multi level inverter is a boon to the inverter technology. Existing system is again modelled with the proposed 2-level & 3-level inverters. Results show that 3-level inverter is the best proposition for up-gradation of the present system.

1. Introduction

In recent years numbers of industrial applications need high power sources. These are mostly in the forms of static power converters. The main objective of static power converter is to produce controlled ac output from a controlled (or sometimes uncontrolled) dc power supply. Some of the examples are adjustable speed drives (ASDs), uninterruptible power supplies (UPS), static VAR compensators, active filters, flexible ac transmission systems (FACTS), voltage compensators etc. For sinusoidal ac outputs, the magnitude, frequency, and phase should be controllable. According to the type of ac output waveform, these topologies can be considered as voltage source inverters (VSIs), where the independently controlled ac output is a voltage waveform. Similarly another topology is known as current source inverters (CSIs), where the current waveform is controlled independently. These structures are still widely used in medium-voltage industrial applications.

AC to AC conversion with an intermediate DC link is most popular[1] among the various static drives for motor. In this category, conventional two-level inverter is still used today in many places. The two-level inverter can only create two different output voltages for the load, i.e. $\frac{Vdc}{2}$ *or* $-\frac{Vdc}{2}$ when the inverter is fed with V_{dc} (Figure 1). There are various drawbacks in a two level inverter or a square wave inverter. To

* *Author for correspondence*

sort out the problem in square wave inverter one new breed of inverter called pulse width modulation (PWM) inverter is developed. Initially conventional square wave inverters were replaced with two level PWM inverters. Very soon it was widely accepted in industries for motor speed control, UPS, SMPS, grid interconnection and for many other applications.

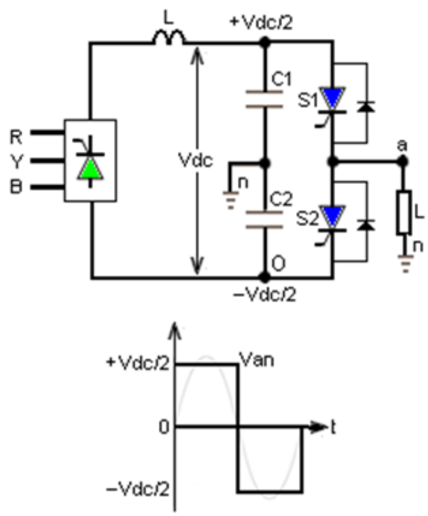

Figure 1. Representation of 2-level inverter showing one leg and output phase voltage.

2. Multi level Inverter

Though the two-level PWM inverter is effective in removing disadvantages of square wave inverter, but it has certain limitations like poor efficiency, high common mode voltage (CMV), harmonic distortions, electromagnetic interferences (EMI), high $\frac{dv}{dt}$ etc. Static power converters, specifically inverters are constructed from power switches and the ac output waveforms are therefore made up of discrete values. For a medium voltage grid, it is troublesome to connect only one power semiconductor switch directly. This has given a thought of increase in the level of inverter. As a result, a multilevel power inverter structure has been introduced as an alternative in high power and medium voltage situations. Multilevel inverter (MLI) is one of the best solutions for the problem in conventional inverters[2]. In multilevel inverter, depending upon the inverter level and type of modulation, several voltage levels are added to each other to create a smoother stepped waveform which is near to sine wave. This concept is originated in year 1975 and since then it is used to control harmonics and common mode voltage (CMV) in the inverter output. Drawbacks of conventional 2-level inverter were removed by developing a basic structure of multilevel inverter called Neutral Point Clamp (NPC) inverter[3]. Thereafter many topologies have been invented by many researchers which replaced many conventional 2-level inverters in medium and high voltage applications. A multilevel inverter not only achieves high power ratings, but also enables the use of renewable energy sources such as photovoltaic, wind and fuel cells.

3. 3-Level Inverter

To better understand multilevel inverters the more conventional three-level diode clamp MLI (DCMLI) is investigated. It is called a three-level inverter since every phase-leg can create three voltages $\frac{Vdc}{2}, 0, -\frac{Vdc}{2}$ as can be seen in Figure 2. A three-level inverter design is similar to that of a conventional two-level inverter but there are twice as many switches in each phase-leg. In between the upper and lower two switches there are diodes, called clamping diodes[4] connected to the neutral midpoint in between two capacitors, marked n in the Figure. These capacitors build up the DC bus, each capacitor is charged with the voltage $\frac{Vdc}{2}$. To create the zero voltage the two switches closest to the midpoint are switched on and the clamping

Table 1. Switching state and output of one leg of 3-level inverter(1-turn on, 0-turn off)

S_1	S_2	S_1'	S_2'	Output pole voltage (V_{ao})	Output phase voltage (V_{an})
1	1	0	0	Vdc	$+\frac{Vdc}{2}$
0	1	1	0	$\frac{Vdc}{2}$	0
0	0	1	1	0	$-\frac{Vdc}{2}$

diodes hold the voltage to zero with the neutral point. Table 1 shows the switching state and output of one leg of 3-level inverter.

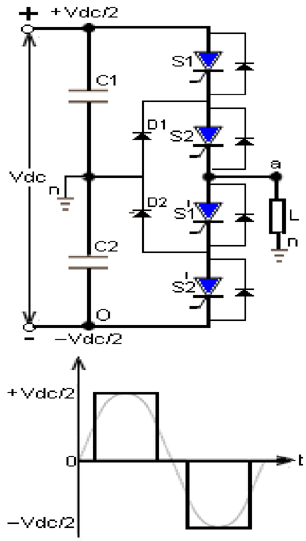

Figure 2. Configuration of one phase leg of 3-level inverter and output

4. Merits and Demerits of Multilevel Inverter

Multilevel inverter has multiple benefits, which are stipulated below:

- It can generate output voltage with very low distortion and low $\frac{dv}{dt}$. $\frac{dv}{dt}$ Lower comes from the small voltage steps.
- CMV level is low, thus motor bearings are less vulnerable to shaft voltage.
- It can operate at lower switching frequency with reduced switching loss compared to the
- more conventional two-level inverters.
- Higher voltage can be generated by increasing the number of voltage levels, without
- stressing the components.
- As the waveforms are near to sinusoidal, harmonic profile is improved.
- Bidirectional power flow is possible enabling the way to interconnect 2 different systems.
- Less electromagnetic interference with neighbouring electronic circuitries.
- Non conventional energy sources like PV cell, fuel cell, and wind power can be
- interconnected with MLI.
- Wide range of frequency variations can be achieved with MLI.
- Besides many advantages multilevel inverter has a few disadvantages. It requires more
- number of power semiconductor switches and its control circuitries. The overall system is
- comparatively expensive and complex in nature.

5. Static Drive in Short Circuit Alternator

Drive system of short circuit alternator is a conventional CSI based 2-level inverter. Its schematic is shown in Figure 3 which is an AC to AC conversion with an intermediate DC link reactor. This is most popular among the various static drives[5]. In this category high rating thyristor based static drives called SFC is in use worldwide for large machines in electric locomotive, gas power plants and pump storage power plants[6-8]. It was a novel idea to implement the SFC technology to run the alternator used in short circuit testing of electrical equipment[9]. To reduce the load on the source and to ease the starting process in large machine, frequency conversion takes place in SFC from a very low value up to the rated value[10]. The source power is drawn from the grid at 33kV level. It is stepped down to 1.72kV level, as SFC operates at this voltage level. Thyristor based controlled rectifier establishes a DC current loop and inverter works as current source inverter (CSI). Most of the time, line side converter acts as rectifier and machine side as inverter. If require they can also reverse their role in the need of applying braking to the running machine. The inverter gives variable voltage variable frequency output to the machine. Basically rectifier sets the DC link current to the desired level by varying the firing angle and inverter provides frequency control. Short circuit alternator starts up as a motor thereafter converted to generator to deliver electrical energy required during the test. Details of these operations are explained in literatures [9,11].

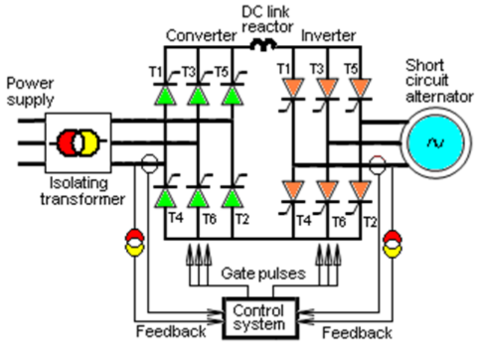

Figure 3. Schematic of static drive for short circuit alternator.

6. Model of Existing System and its Validation

A MATLAB/Simulink[12] model (Figure 4) of the existing system is created with the data (see appendix) drawn from the working system. In Simulink model, one three phase source, one step down transformer, two thyristor bridges are taken. A reactor is placed in between the two bridges. Step down transformer is inside the rectifier block. Rectifier and inverter both are in six pulse configuration.

For validation of the model, simulated waveforms are compared with the waveforms from the actual

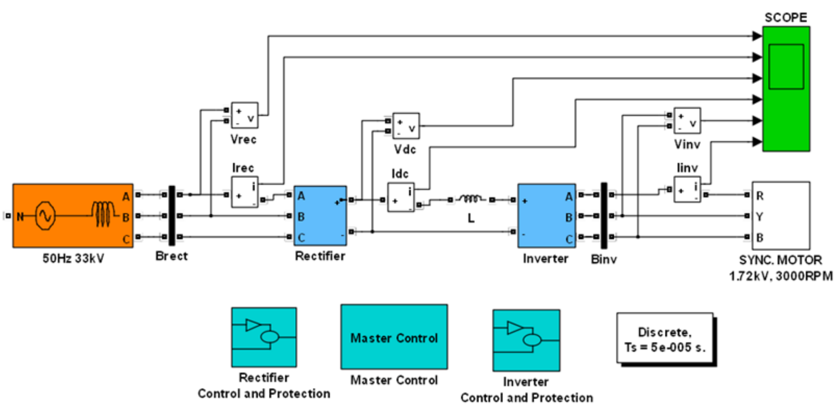

Figure 4. Simulink model of existing SFC used in short circuit alternator.

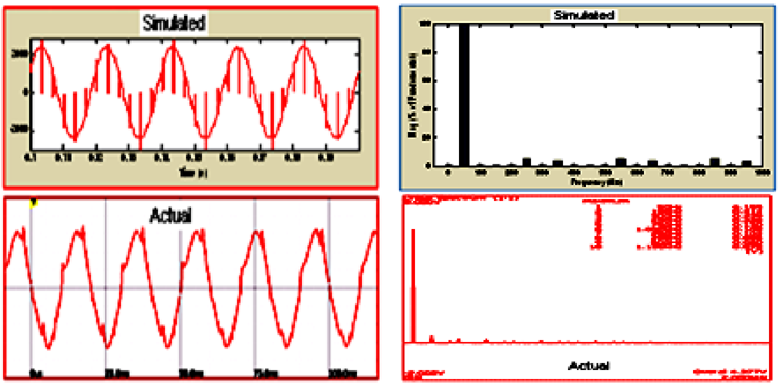

Figure 5. Machine voltage & its frequency spectrum.

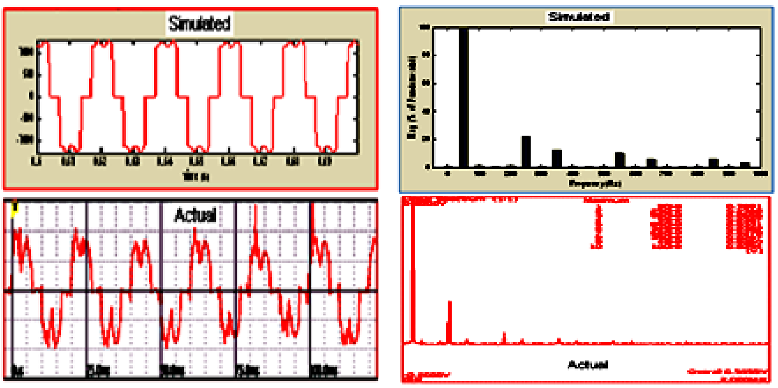

Figure 6. Machine current & its frequency spectrum.

system. Machine voltage, current and their frequency spectrums are determined and authenticated for the validation process (Figure 5 & 6). Wave shapes and FFT analyses of original system and modelled system Analysis of Simulink model reveals that CSI based SFC feeds current at machine terminals containing more than 30% THD. Voltage is also highly distorted at 20% THD level. CMV is measured as 52.18 V_{rms}. Presence of high THD and CMV induce voltages in the shaft of the machine. It also affects the insulation of machine winding in long run. Shaft voltage causes the flow of current through machine bearings. These bearing currents are normally two types; conduction mode current and discharge mode current. The machine experimented here has insulated bearing at one end, hence conduction mode current is negligible in this case. Only discharge mode current is possible to flow in the grounded bearing. The discharge mode current, known as electric discharge machining (EDM) is measured with high speed oscilloscope and shown in Figure 7. Each EDM pulses have high level of energy which may deteriorate the shaft and bearing surfaces by eroding the material. This may affect machine operations by early ageing of shaft and bearing. EDM also creates electromagnetic interferences in the neighbouring electronic circuits.

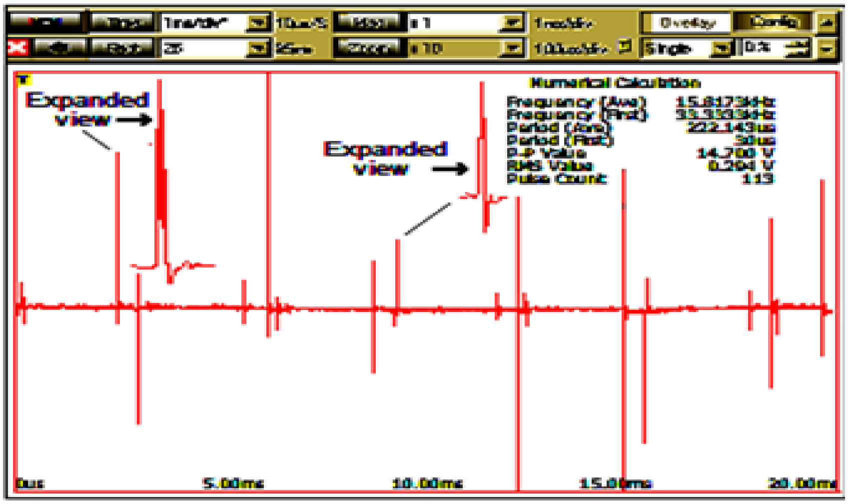

Figure 7. EDM due to the presence of shaft voltage.

7. Proposed Application of MLI in Short Circuit Alternator

Simulation results don't suggest for the long term use of existing CSI based converter for the short circuit alternator. After studying the benefits of multilevel inverter it is thought of to implement the same on the existing drive system of short circuit alternator. To justify the purpose of proposed inverter replacement, some experimental evidences are necessary. It is obvious that direct practical experimentation is not advisable on this large operating system. Virtual experimentation is the best way to give any concrete suggestion. With this concept a 2-level PWM inverter is put in place of CSI in the Simulink model. After drawing results of 2-level PWM inverter is removed and a 3-level PWM inverter is put in that place. The waveforms and frequency spectrums of motor voltage and motor current are shown in Figure 8 and 9.

8. Result and Discussion

After experimenting 2-level and 3-level PWM inverters in the existing system all the simulation results are compared and tabulated in Table 2. It is observed from the Table that THD which were extremely high for voltage and current at motor terminals in the existing system is drastically got reduced in both 2-level and 3-level PWM inverters. The higher topology of MLI may also be experimented but there will not be much difference in results; rather circuit complexity and cost will increase.

9. Conclusion

It is well proven that old conventional inverters are not suitable for the present power system when the grid disciplines are getting stringent. The thyristor based CSIs are the producers of high level of harmonics, common mode voltage and electromagnetic interferences. Real time study and virtual study both confirm these aspects of CSI. There had been two objectives of this study. First one was to analyse in detail about the existing converter-inverter based drive for short circuit alternator. The second objective was to propose a suitable inverter

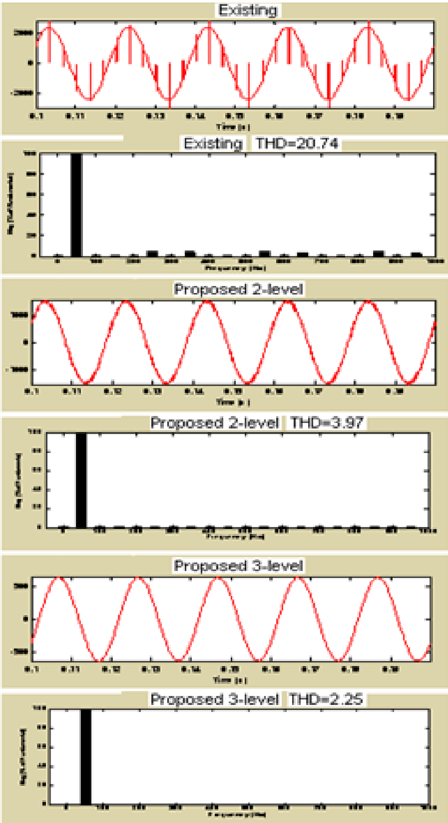

Figure 8. Motor terminal voltages & frequency spectrum.

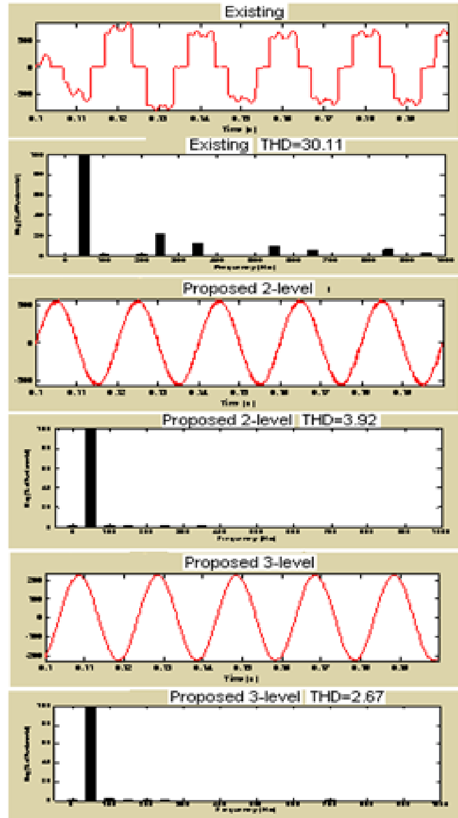

Figure 9. Motor currents & frequency spectrum.

Table 2. Comparison of existing CSI, proposed 2 level and 3 level inverter

PARAMETER / *Inverter*	% THD source voltage	% THD source current	% THD motor voltage	% THD motor current	Common mode voltage V_{rms}
Existing system	2.46	18.12	20.74	30.11	52.18
2-level inverter	12.80	10.23	3.97	3.92	15.49
3-level inverter	**3.39**	**4.88**	**2.25**	**2.67**	**11.99**

as a replacement of the current one for the machine. After studying the existing system it is suggested that application of MLIs are the most suitable for replacing the present CSI. The benefits foreseen are low THD level both in the source and load side, improvement in source power factor and lower EMIs. As power electronics components are getting cheaper and available in higher ratings, it will be a good scheme, if implemented. This will enhance the life of the overall system. Though this study is conducted on a specific machine but its outcome is applicable to the other machines with static drives.

10. Acknowledgement

Author is thankful to the management of Central Power Research Institute for supporting this work.

11. References

1. Bhowmik S, Spee R. A guide to the application oriented selection of AC/AC converter topologies. IEEE Transactions on Power Electronics. 1990 Apr; 8(2):156–63.
2. Akagi H, Doumoto T. An approach to eliminating high-frequency shaft voltage and ground leakage current from an inverter-driven motor. IEEE Trans Ind Appl. 2004; 40(4):1162–9.
3. Nabae A, Takahashi I, Akagi H. A New Neutral-point Clamped PWM inverter. IEEE Transaction on Industrial Applications. 1981; IA-17:518–23.
4. Rodriguez J, Jih-Sheng L, Peng FZ. Multilevel inverters: a survey of topologies, controls, and applications. IEEE Transactions on Industrial Electronics. 2002 Aug; 49(4):724–38.
5. Thanga RC, Srivastava SP, Agrawal P. Energy efficient control of three-phase induction motor-A review. International Journal of Computer and Electrical Engineering. 2009; 1(1):1793–8198.
6. Robert B, Fisher PE. Introduction of static frequency converters on SEPTA's 25 Hz commuter rail system. Proc. ASME/IEEE Railroad Conf.; 1990. p. 149–55.
7. Park SH, Hwang S-H, Kim J-M. Ryu H-S, Lee J-H. A starting- up control algorithm of large synchronous generation motor for gas turbosets. Proc. IEEE Int Symp Ind Electron; 2008. p. 502–8.
8. Zhang YZ. Study of process of starting pumped storage machines by static frequency converter with field current controlled. Proc IEEE Int Conf Signal Process Syst; 2010. p. V1-224–7
9. Datta AK, Dubey M, Mondal NR, Raghavaiah BV. Motor-less operation of Short Circuit generator – A CPRI Perspective. International Conference on Electrical Power and Energy Systems (ICEPES-2010); 2010 Aug 26-28; Bhopal. p. 439–45.
10. Peterson T, Frank K. Starting of large synchronous motor using static frequency converter. Proc IEEE Summer Meet Int Symp High Power Testing; 1971 Jul 18-23; Portland. p. 172–9.
11. Datta AK, Ansari MA, Mondal NR, Raghavaiah BV. A novel use of power electronics: prime mover-less alternator with static drive & excitation system. International Journal of Electronics & Communication Technology. 2012 3(1):472–5.
12. The MathWorks™, Inc., USA, Release 2008a (R2008a).

APPENDIX

Details of Short Circuit Alternator	*Parameter for System Model*
Type: Synchronous generator	Input source: 33 kV, three phase
Rated output voltage: 12.5 kV	Transformer nominal power: 3.5 MVA
Rated current: 69 kA	Transformer primary input, Delta: 33 KV, 50Hz
Rated frequency: 50 Hz	Transformer secondary output, Star: 1.72 KV
Rated power: 1500 MVA	Thyristor bridge: 3 arms
Speed: 3000 RPM	Snubber resistance: 2000 Ω
Duty: Intermittent	Snubber capacitance: 0.1 μF
Excitation voltage: 100 VDC	Link reactor: 4.8 mH
Excitation current: 1680 A	Base voltage: 12 kV
Class of insulation: F	X/R ratio: 20
Type of cooling: Forced air	Motor voltage: 1.72 kV
Type of protection: IP 54	3-ph short circuit level at base voltage: 1500 MVA