# NEW METHODS OF CONTROL FOR HIGH-SPEED MACHINES

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_Abstract: This quarterly report describes the progress made on the topic titled above and also defines a direction for the research to progress. Currently the research is in the phase of literature review. Most of the sources are from IEEE along with a few from ResearchGate. The current focus of the review on the actual design specification of the high-speed machine (HSM) along with the topology and technique of controller._

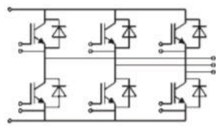
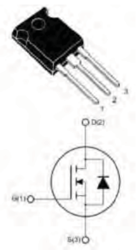
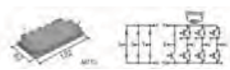
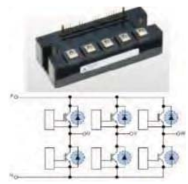
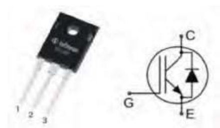
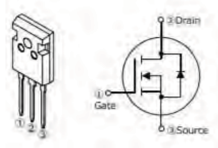
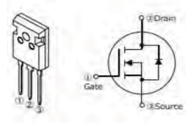
_Keywords: High-speed generator, automotive, multi-level converter_

## 1 Introduction:

With mankind's ever increase in use of electricity as source of energy, we are in need of compact and modular solutions to solve our future's energy demand. Recently, high-speed machines (HSMs) have gained attention of the scientific community in the field of more electric aircraft (MEA), distributed electric generation (DEG) and automotive applications. For this dissertation the field of application is automotive engineering. HSMs are today a common solution on power generation units based on micro-gas and air turbines, both for grid connected and stand-alone applications. For the above titled topic a high-speed generator (HSG) is chosen as the subject of research. A HSG is a high power to weight ratio machine, which operates in the range of 1 - 100 kW and 100,000 - 10,000 rpm. A HSG generates electrical power at high frequency usually 10 - 20 times line frequency due to the speed of its rotation. This calls for the power to be rectified first, then filtered and finally to be used by auxiliaries like DC-DC or DC-AC converters and inverters. Hence, it is of paramount importance to develop an efficient control scheme to maximize power gain from the HSG and minimize harmonic injection into the auxiliaries by the HSG. The controller topology and schematic, it's gate drive control along with all ancillaries is the prospective problem statement of this topic.

## 2 Literature review:

Initially the task was to define automotive ambient conditions like temperature, humidity, vibration and other supply chain parameters like lifetime, supply and failure rate. These were referenced from BOSCH's requirements for automotive semiconductors [1]. Also the task was to find out some examples of prospective semiconductor switches to be used here. Preference was given to SiC chemistry due to it's high frequency and high voltage operation. The selected voltage and current rating were 600 – 800 V at 55 – 100 A. This was chosen because there is high probability that automotive manufacturers will employ HV architecture for their power-trains [2]. The following table summarizes the findings.

| Manufacturer | Code | Type | Rating | Module |
|---|---|---|---|---|
| https://www.semikron.com/dl/service-support/downloads/download/semikron-datasheet-semix101gd066hds-27891200/ | SEMiX101GD066HDs | IGBT | 600 V, 100 A |  |
| http://www.st.com/content/ccc/resource/technical/document/datasheet/group3/0d/4c/81/d0/a5/9b/4a/27/DM00293874/files/DM00293874.pdf/jcr:content/translations/en.DM00293874.pdf | SCTW100N65G2AG | Power MOSFET | 650 V, 85 A, 200 °C |  |
| http://www.fujielectric.com/products/semiconductor/model/sic/hybrid.html | 7MSR100VAB060-50 | IGBT | 600 V, 100 A |  |
| http://www.mitsubishielectric.com/semiconductors/catalog/pdf/sicpowermodule_e_201505.pdf | PMH200CS1D060 | SiC + SBD | 600 V, 200 A |  |
| https://www.infineon.com/dgdl/Infineon-AIKW50N65DH5-DS-v02_01-EN.pdf?fileId=5546d4625cc9456a015d08132bd27f3c | AIKW50N65DH5 | IGBT + Diode | 650 V, 54 A, 175 °C |  |
| https://felib.fujielectric.co.jp/download/details.htm?dataid=19947488&site=global&lang=en | FMW60N025S2HF | MOSFET | 600 V, 60 A, 100°C |  |
| http://www.rohm.com/web/global/datasheet/SCT3017AL/sct3017al-e | SCT3022AL | N Channel SiC Power MOSFET | 650 V, 83 A, 100°C |  |

### 2.1 Research paper review:

Over the period of 4 months many papers were read and analyzed pertaining to design and development trends in HSMs along with controller topologies and strategies. It became evident that the control topology would be multi-level inverters due to their reduction in indiviudal switch rating and wave shaping function. Two of the papers are summarized below.

In a paper by D. Gerada, A. Mebarki, N. L. Brown, C. Gerada, Member, IEEE, A. Cavagnino, Senior Member, IEEE, and A. Boglietti, Fellow, IEEE, the authors have described trends in HSMs under the title '**High-Speed Electrical Machines: Technologies, Trends, and Developments [3]**'. The authors have hilighted application areas for high speed machines and their resuting system benefit. In one such application, the electrical machine is placed on the same shaft as the turbine and the compressor wheels in a turbocharger. Driveline efficiency can be further improved by installing an additional power turbine and a high-speed machine at the downstream of the turbocharger to extract waste heat from the exhaust gases, which is often called turbocompounding. The authors illustrates a flywheel developed by Williams Hybrid Power, used within the Porsche 911 GT3R. This flywheel rotates at 40,000 r/min and is used to generate/motorize up to 120 kW to the front-axle motors. The authors have briefly described turbomolecular pumps which are used to obtain and maintain a high vacuum. The relevant application for our topic shown by the authors is in using microturbines as range extenders within serial hybrid and electric vehicles, as a power unit that can charge the vehicle's batteries. The authors illustrate a 50-kW 80,000-r/min microturbine developed by Bladon and claims that such a technology can be just 5% of the size, weight, and parts of an equivalent piston engine. In the final section of the paper the authors have done benchmarking of the aforementioned machines.

A literature survey on **'Different Topologies and Control Techniques of Multi-level inverter [4]'** carried out by Zina Boussada, Omessaad Elbeji and Mouna Benhamed from the Photovoltaic Wind and Geothermal Systems Research Unit in the department of Electrical engineering at the National Engineering school of Gabes in Tunisia highlights some mainstream topologies and control schemes for (Multi-Level Inverters) MLIs. The authors have presented three topologies viz. 1] Diode Clamped Converter (DCC), 2] Flying Capacitor Converter (FCC) and 3] Cascaded Converter (CC) and three control techniques which are 1] Pulse Width Modulation (PWM), 2] Space Vector Modulation (SVM) and 3] Space Vector Control (SVC).

The DCC topology is the most commonly used MLI. Advantages of this type of topology are; 1] Minimization of capacitor requirements. 2] High efficiency for fundamental frequency switching, and 3] Low harmonic content with increase in number of levels is high enough. Concerning disadvantages the authors cite that the difficulty in controlling the intermediate DC levels will tend to unbalanced discharge.

To achieve different voltage levels in the output signals, FCC uses several floating capacitors in each phase instead the clamped diodes in DCC structure. Advantages of FCC topology are, 1] Clamping diodes are not needed, 2] The topology has switching redundancy within the phase, that can be used to balance flying capacitors then just one dc source is needed. 3] Capacitors enables the inverter to ride through sort duration outages and deep voltage sags. Concerning disadvantages the authors cite that, it is an expensive topology due to the large number of capacitors. Added to that, switching utilization and efficiency are poor for real power transmission and voltage tracking of all capacitor is complex.

The cascaded converter called also full-bridge converter is a combination of two single-phase inverters with independent voltage sources. The main advantages of the Cascaded Converter topology are: 1] The topology is based on full-bridge converters, which when connected each other which makes the scheme simple and modular. Further the authors cite that the main drawback is that this topology cannot be applied at lower power levels.

Next, the authors briefly describe the three control technique aforementioned.

Multi-level sinusoidal PWM uses several triangular-carrier signals while keeping only one modulating sinusoidal signal. (N-1) triangular-carrier is needed for N-level inverter. Each carrier is compared, at every instant with the modulating signal. If the modulating signal is greater than the carrier, the switch is switched “ON”.

SVM can be extended easily to all multilevel inverters. It’s advantages are 1] Low current ripple and easy implementation by a FPGA. These vector diagrams are universal regardless of the type of multilevel inverter. In other words, is valid for five-level diode-clamped, capacitor clamped, or cascaded inverter. The adjacent three vectors can synthesize a desired voltage vector by computing the duty cycle for each vector.

SVC is a control method based on the space-vector theory. This technique of control, called SVC, works with low switching frequencies and it is not as the SVM because it does not generate the mean value of the desired load voltage in every switching interval. The main idea in SVC is to deliver to the load a voltage vector that minimizes the space error or distance to the reference vector. The high density of vectors produced by high-level inverter will generate only small errors in relation to the reference vector; it is, therefore, unnecessary to use a more complex modulation scheme involving the three vectors adjacent to the reference. This method is simple and attractive for high number of levels. The authors stress on the fact that as the number of levels decreases, the error in terms of the generated vectors with respect to the reference will be higher; this will increase the load current ripple.

## 3 Future direction and conclusion:

The literature reviewed up till now points to a 20 – 50 kRpm Machine at a power rating of 50 – 150 kW. The desired control topology would be multi-level converter running on an appropriately investigated and studied control technique. Further research would also focus on MRAS (Model Reference Adaptive System) to estimate machine parameters online for better control. It would also be fruitful to theorize a hybrid NPC+FCC+CC topology.

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