Thoughts on Technology development of Inverter and Digital Controller for Direct-Driven GMI Wind Turbine Generator

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The Ohio State University, April, 2009

1. Overall system description

The overall system description of the direct-driven GMI permanent magnets wind turbine generator is given in Fig. 1.

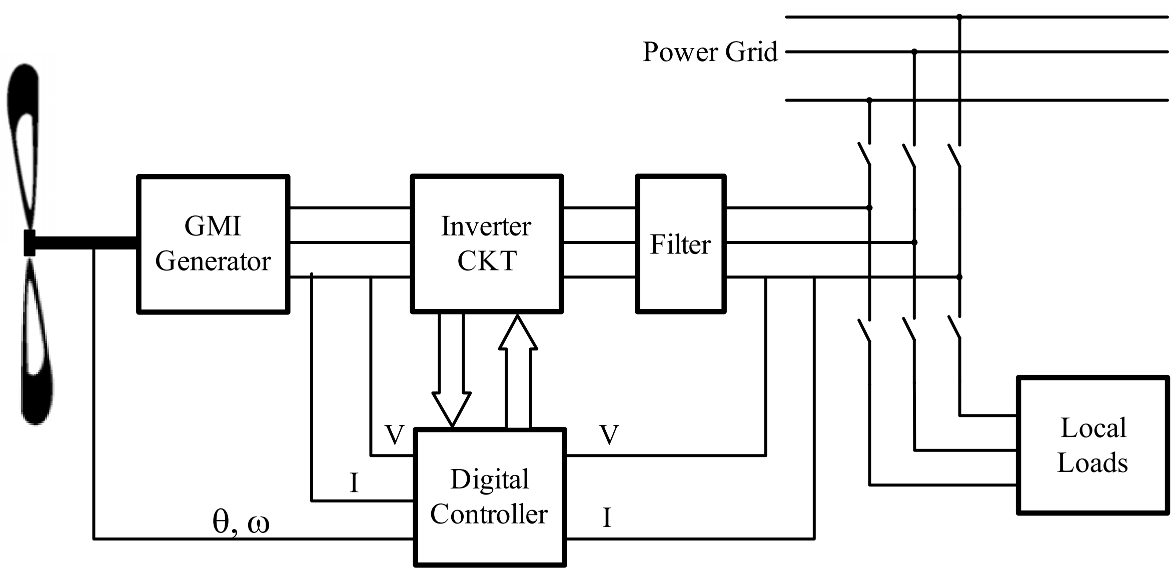

Fig. 1. Overall system description of direct-driven wind turbine generator system

Assuming we get the GMI PM wind turbine generator right, we still need to get the inverter and digital controller technology right to make the overall wind turbine generator function well. Plus, we need to get the mechanical components including wind turbine blades, tower, and yawing devices in place to make the wind turbine generator system complete. Like the PM generator itself, the inverter and digital controller are two components considered very technology intensive and through innovative design we can increase the competitive advantages of our products over the others.

2. **Solution to inverter** – the solution to inverters varies, depending on the power, wattage, and speed range it is expected to handle. My basic idea is that the inverter configuration is based on a modular approach that is flexible and adaptive to various applications. As shown in the following figure, we are going to have a basic building-block, M1, for 20-50kw, consisting of two back-to-back inverters linked by DC bus voltages.

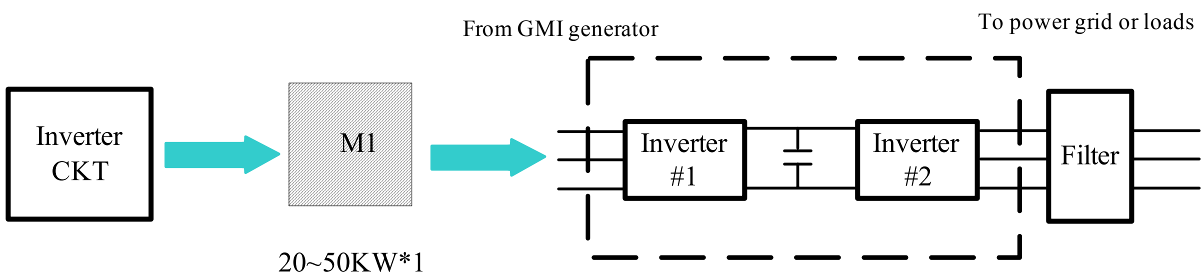

Fig. 2. Basic modular inverter as building-block

The first inverter in the module functions as a PWM rectifier and also a DC-DC booster. With the first inverter in the module, voltages generated by the GMI generator in variable frequency and magnitude are conditioned to a fixed DC voltage. The second inverter inverts the DC voltage to AC voltage of fixed frequency and magnitude suitable for power grid connection or as a stand-alone generator supplying electricity to local loads. A dedicated LCL filter is to be designed for the use between the inverter and power grid (or local loads) to minimize harmonics to meet utility regulations.

If we use two of power module as shown in parallel in Fig. 3, we will have a generating system with a power handling capability up to 100kw. Each power module is identical to that in Fig. 2 but the control circuits are doubled and the filter is to be re-designed for optimal filtering performance and smaller size.

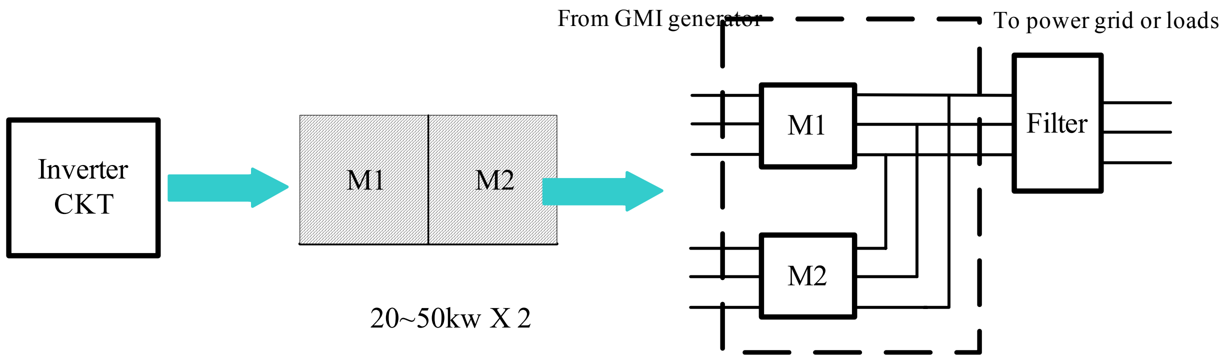

Fig. 3. Inverter based on two modules to double power capability

If we put two power modules in series first to form a so-called three-level inverter and then parallel the two three-level inverters (essentially use 4 units of M1 building blocks), we have a generating system with a power handling capability up to 200kw or much larger in megawatts with large modules.

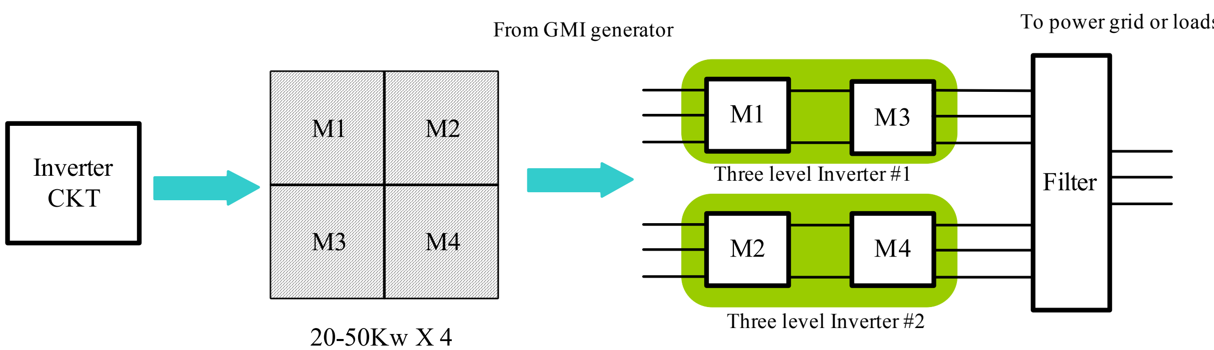

Fig. 4. Two 3-level inverters for much large power capability using 4 modules of building-block

Note, however, that using two modules in series to build a three-level inverter is not as simple as it sounds because of the technology complexity and related control hardware and software involved in three-level inverters. But the benefits of three-level inverter are comprehensive, including much better performance and great potentials if we have a desire to get into the mega-watt wind turbine generator technologies.

3. **Solution to digital controller** – The Digital Controller is considered the brain of the overall wind turbine generator and deserves necessary attentions. As described in the Fig. 1, the controller takes a lot of feedback signals as the inputs (the wind speed and direction, PM generator rotor position and speed, generator current and voltage, DC bus current and voltage, power grid current and voltage), calculate the needed control commands, and output various control signals to the control circuits for inverters. The digital controller includes development of both a hardware platform and the control software. For multiple power modules in parallel or parallel/series connection, the input and output signals will be multiplied and the digital controller will need more interface circuits. To accommodate the increased complexity the CPU needs to have sufficient computing power and memory size.

Many other functions of the wind turbine generator should be also built into the controller such automatic sequence for starting and shut-down of the wind turbine system, over voltage and over current protections, self monitoring and diagnosis, communications to the operators, automatic power grid (or loads) switching in and out, etc. The controller will have all the raw data available that a complete Data Monitoring and Logging system could want.

4. Estimated costs and timeline (430-530)

Three approaches are suggested to fulfill the inverter and controller portion of the wind turbine generator systems and each of them is designed to meet certain expectations. The three approaches are explained below with the time and cost estimation.

a. ***Approach 1*** : 3-4 months and $35K

In this approach, we will purchase two small inverters, off the shelf or slightly modified, and configure them into M1 building block for the power-conditioning unit. To control the inverter, we will develop the hardware and software compatible with the power module for functionalities as described above. The results of this approach include a fully functional inverter unit, the interface filter and the home-made digital controller hardware and software. This set of inverter and controller technology is suitable for 20- 50kw wind turbine generator operation. The digital controller is ready for upgrading to an integrated unit of M1 and M2 in the power range of 40-100kw wind turbine generator operation. However the upgrading is not included in this approach in terms of time and budget. This approach can be considered 50% of Approach 2.

b. ***Approach 2***: 6-8 months and $60-70K

Approach 2 includes everything achievable in Approach 1, accounting for 50% of the work in this approach. In Approach 2, for inverter topology, we will use two units of M1 and M2 – similarly purchased as what we did in Approach 1. The main work of the approach is to integrate the two units for a larger one capable of power delivering up to 100kw. In addition to what should be done in Approach 1, the main work in this approach will be to develop hardware and software to control the two units of power module coordinately. The results of this approach include a fully functional inverter unit based on two power modules, the interface filter and the home-made digital controller software and hardware. This set of inverter and controller technology is suitable for 100kw wind turbine generator. But this unit is **not** meant for any upgrading to a high power inverter using four power modules.

c. **Approach 3:** 12 months and $100-120k

In Approach 3, we will develop our own power modules that not only can satisfy the requirements for a single module M1 application, but also M1 and M2 parallel application. More importantly, this power module will be suitable for development of the so-called three-level inverter that is needed for power handling capability of 200kw and in megawatts range. In this approach, we will develop technologies completely home-made, from single power module development, two modules in parallel, two modules in series for three-level inverter and finally two three level-inverter in parallel. The related hardware and software for digital controller will be also developed. The inverter topology and digital controller are suitable for further upgrading to the scale of megawatt wind turbine applications. This approach can be divided into three stages and each can accomplish the goals specified in Approach 1 and Approach 2 respectively. This is the choice if the company has a long-term goal of megawatt wind turbine technologies and market.

5. **Roadmap discussion**

There are three roadmaps to take as described above:

1) Approach 1 only – this is the least expensive one in terms of time and money and will get the GMI 20~50kw wind turbine generators to function properly. The inverter will be purchased and perhaps we can find a vender later in China to supply, and hopefully at a reasonable price. But the results end at the power rating of 50kw for a single unit.

2) Approach 2 only – this is actually the extension of Approach 1 and will double the power rating by a factor of two with the added controller technologies. The inverter is purchased as was done in Approach 1. The digital controller hardware and software are designed and owned by our company.

3) Approach 3 – this encompasses everything in the inverter and the digital controller technologies. All segments of the inverter and digital controller will be designed by ourselves and later the inverter and digital controller can be contracted to a Chinese manufacturer for mass production. Attention will be given to using the most advanced collection of off the shelf components and could involve partnering with an existing inverter company to modify or co-develop the next generation of this technology with us. This is a more ambitious approach than the other two. It also takes a longer time and bigger financial resource. However, this is also the most useful one to secure growth potentials in future competitive market.

Mac's notes of his conversation with Longya mid-day today 4-16-09.

1. this technology could be downward modified for the 10kw and under family of turbines.

2. Use of the two stage PWM rectifier and Multi Gated Inverter will achieve conversion efficiencies ranging from 95% at the softest end of the production moving up and maintaining around 97% when winds are more suitable.

3. Approaches 1 and 2 are most rapid and use the existing inverters from a third party. Home-made for all approaches will be the hardware platform and software for the digital controller. Longya has worked with Semikron for almost 15 years on other projects. He knows Jason Lia of EMPC very well from the IEEE and both being faculty members at different Engineering Schools, Longya at OSU and Jason at Virginia Polytechnic, but he is unfamiliar with their products. These approaches could lead to working with such vendors to modify or co-develop improved systems for us and perhaps others.

4. The digital controller would developed to meet the 20-100kw requirements in Approaches 1and 2. As listed in Sect 3, there are a great many inputs from sensors and feedback loops that supply the information for the Digital Signal Processor/CPU. These are divided into two source area – the Generator/Inverter and the Grid Conditions. Both sets of information are routed and prioritized in an "arbitrator" module that starts the interpretation and decision process, but above the "arbitrator" is the higher-level programming and interface with the operators and service people.

5. Each turbine size would call for a suitably sized LCL Filter to avoid over sizing with associated additional cost.

6. Choosing the approach will involve weighing the company's long-term goals. Will we move into the over 100k market? Do we want to add as much value and own as much of the IP in our products as possible? Does the production time line

work with the turbine/generator development schedule to let us take what may be a more strategic path – Approach 3.

7. The budgets stated, as this entire preliminary proposal, are general estimates that would cover the labor and materials his development team of graduate/doctoral assistants would require. A larger more refined proposal would include more exact budget and time line information. Also, discussion of Longya's compensation and time requirements would begin to be explored, as well as the value of his Intellectual Property.