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# Quarterly Report
DOE Grant Number :- DE-FG36-99G010390

Project Title:- A DSP based power electronics interface for alternate/renewable energy systems.

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*Abstract:* - This report is an update on the research project involving the implementation of a DSP based power electronics interface for alternate/renewable energy systems, that was funded by the Department of Energy under the Inventions and Innovations program.

## *Objective:*

The objective of this research is to develop an utility interface (dc to ac converter) suitable to interconnect alternate/renewable energy sources to the utility system. The DSP based power electronics interface in comparison with existing methods will excel in terms of efficiency, reliability and cost. Moreover DSP-based control provides the flexibility to upgrade/modify control algorithms to meet specific system requirements. The proposed interface will be capable of maintaining stiffness of the ac voltages at the point of common coupling regardless of variation in the input dc bus voltage. This will be achieved without the addition of any extra components to the basic interface topology but by inherently controlling the inverter switching strategy in accordance to the input voltage variation.

## *Technical Progress:*

The block diagram of the proposed DSP based interface is shown in Figure 1. Texas Instruments DSP TMS320F240 will be used in the implementation of the controller. The DSP(TMS320F240) which is chosen to implement the proposed algorithm not only provides the computational capability but also integrates all the power electronics peripherals necessary to implement any such system. These peripherals include PWM generators, timers, ADC etc.

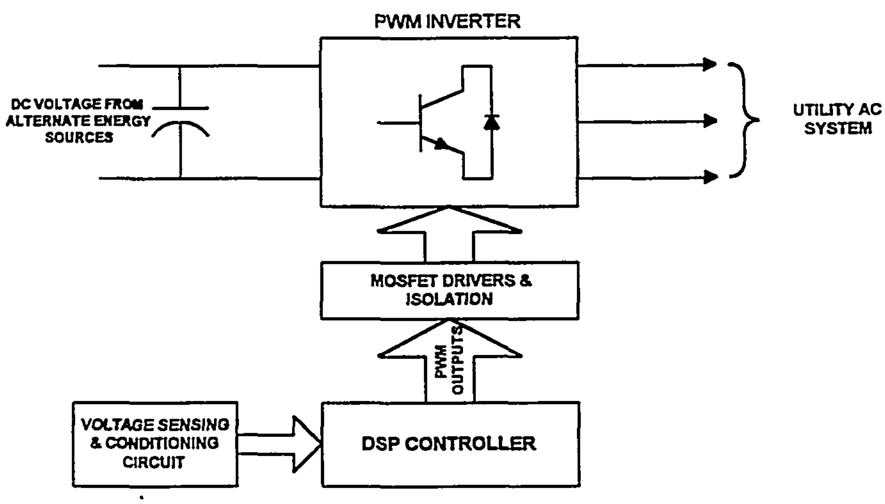




Fig. 1 Block diagram of the proposed DSP based interface.

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a scale and in a manner from which best practices for deployment/process control were determined.

Examination of photographs of past work shows clear signs of failure to formulate the polyurethane for the conditions to be encountered during the reaction (Earl Doyle, consultant). The reactivity of polyurethane raw material roughly doubles every 10°C requiring that the polyurethane formulation be matched to the conditions encountered. If the reaction is too slow (reaction temperature is significantly less than the temperature for which the formulation was designed), gas evolves before the material hardens allowing the gas to escape and the resulting material collapse - Figure 4-24 of Loeppke et al. If the reaction is too fast (reaction temperature is greater than the temperature for which the formulation was designed), the material hardens too soon and subsequent gas pressure rips/fractures the material apart - Figure 4-20 & 4-28 of Loeppke et al.

An important aspect of the current approach is to learn from other industries where polyurethane grouting is being applied. An unexpected benefit of this learning process has been the identification of new two-part, high-temperature polyurethane foam used to insulate 400°F underground steam lines. Since lost circulation is an issue where casing is set (above the reservoir), 400°F should cover more than 90% of all geothermal lost circulation zones.

Having established best practices for process control, the project focus is shifting to developing deployment mechanisms and polyurethane formulations. Previous field tests were done using a reusable two-chamber canister that was lowered down the well on the end of the drill pipe. Such a canister can deliver only a limited supply of chemical, which makes expansion critical, and the use of a reusable container creates a cleanup waste disposal problem. What is needed is a disposable, drillable canister and/or a means of pumping the material down the well into the loss zone. Deployment options depend upon the chemical formulation (e.g. one or two part polyurethane) and mode in which the chemicals are to be used.

Incompetent borehole problems and lost circulation can be solved in two modes using polyurethane:

- *Plug and drill.* In this mode, each loss zone is plugged before drilling continues. Normally the bit is tripped for each zone.
- *Shoe-to- shoe wellbore lining.* In this mode, polyurethane is used to line-the-hole, preferably by continuous injection, from casing point to casing point. Continuous injection could be achieved, for example, by sliding a straddle packer along the hole injecting polyurethane as the packer is moved. Lining-the-hole shoe-to-shoe would be done to assure a good cement job. In this approach to making hole, drilling could switch to underbalanced aerated fluids. Normally this approach to drilling can not be applied to lost circulation zones because of the problems associated with subsequently achieving a good cement job.

The need for new chemical formulations is being investigated. Commercially available one-part formulations are only useable below 180°F. This temperature would be inadequate for many geothermal applications. High-temperature (400°F) commercially available chemical two-part formulations are available; however, these formulations may not be appropriate for downhole application (high viscosity and awkward mixing ratios). These materials plus past tests done by Earl Doyle demonstrate that high temperature formulations can be made. Polyurethane foams can be made from either one or two component raw material formulations.

One-component foams can be prepolymer mixtures that are catalyzed by water or moisture. Another class of one-component foams is "blocked foams" for which the reaction is initiated by heating. A blowing agent may be added to the formulation or $CO_2$ produced by the polymerization reaction of isocyanate and water may produce expansion (called water blown foam). The blowing agents typically added to construction and civil engineering polyurethanes usually have low vapor pressures (e.g. HCFC 141b vapor pressure is 70 psi. at 200°F), limiting their use at depth. The vapor pressure of $CO_2$ is higher making water blown foams more suitable at depth. The design of a successful deployment scheme depends upon an understanding of the polyurethane formulation, best polyurethane plugging practices, and effects of temperature and pressure on the reaction.

**Research Results**

A successful polyurethane lost-circulation plug should be able to withstand 1000 psi across the plug while leaking at an acceptably low rate. 1000 psi is needed to withstand the pressures when tripping and cementing. The quantity and rate of injection must be sufficient for the polyurethane to sweep out the mud and/or formation water so that the polyurethane becomes the continuous phase (Figure 1). If insufficient polyurethane is used, only granules of polyurethane dispersed in the mud are formed. These are easily washed away. If polyurethane is injected at too low a rate it can be washed away by cross flow before it sets. When adequate foam is used, a closed cell high density (> 4 $lb/ft^3$) plug results. Such plugs have been lab tested at 450 psi. (Mansure and Westmoreland). The measured leakage was equivalent, for a 12.25" borehole in a ten-foot-long lost circulation zone, to less than 0.05BBL/day per 100 psi, an acceptable low-loss rate. This leakage rate is less than one millionth of the leakage before the foam was injected.

While polyurethane expansion can be beneficial, tests have shown that expansion is not required to form a good plug. Advantages of expansion are that it decreases the cost of a plug and helps squeeze material into the loss zone. A plug that is not squeezed into the loss zone, one that is merely on the surface of the borehole, will not last. It can be broken off by subsequent drilling and drill pipe motion. Merely pouring polyurethane into a well will not result in penetration into the loss zone. Penetration into the loss zone was only reliably achieved by applying hydraulic pressure, not by expansion. Too much expansion produced open-celled, weak, leaky plugs.

Plug formation best practices include:

- the loss zone must be packed off and the polyurethane squeezed into the loss zone,
- sufficient polyurethane must be injected to sweep out the mud and become the continuous phase,
- injection time should be longer than the gel time so that the material starts to set (becomes viscous) during injection.

Initially, before the raw materials react to form polyurethane foams, their density may be heavier than the drilling mud. However, lab tests show that this density difference is not always sufficient to overcome the gel strength of the mud allowing the raw material to sink into loss zones. Thus, one cannot rely on raw material flowing out into the loss zone due to gravity. The only way to insure raw material goes out into the loss zone is to push it there. This requires some means of packing the hole off and forcing the raw material to flow into the loss zone.

Both the quantity and rate of injection must be sufficient for the polyurethane to sweep out the mud and/or formation water so that the polyurethane becomes the continuous phase (Figures 2 & 3). Granules of polyurethane dispersed in the mud were formed when insufficient polyurethane was used. While the granules were sufficient to turn the mud white, when pressure was applied, the granules were swept away in a matter of seconds. Injecting more, but still inadequate, polyurethane resulted in a porous material much like that used for thermal insulation in the construction industry. Such material, while very open celled, allowed the formation of a mud cake; however, the mud cake did not resist pressure above 20 psi. When adequate polyurethane was injected, a hard, dense, almost-closed-cell plug was formed. Also, if polyurethane is injected at too slow a rate, it can be washed away by cross-flow before it sets.

It is important that the injection time and gel time be in the right relationship. If the polyurethane sets too fast, material in the wellbore sets before an adequate volume is injected and all the fractures plug. In the extreme case, tests where the gel time was much too fast, the polyurethane set before any of it entered the loss zone. In tests where the gel time was too slow, injection ended before any of the material set resulting in a poor plug that was porous, permeable, and contained mud channels.

Figure 2 explains the critical relationship between injection time and gel time. The initial flow path for squeezing polyurethane into the loss zones is into the wider, more permeable, channel (top channel). If the polyurethane in the top channel does not gel during injection, there may be no flow into the lower channel. If the polyurethane gels during injection, the more permeable flow channels close off. Subsequent polyurethane entering permeable channels is compacted forming a hard impermeable plug. Also, subsequent polyurethane injected is forced into new, less permeable channels (lower channel). Thus, by timing the gel to occur during injection and by injecting an adequate quantity of polyurethane, all the loss zone channels can be filled. Subsequent polyurethane injected is packed into a hard impermeable plug, one that does not leak and can withstand high pressures.

**Future Plans**

Emplacement techniques to deliver polyurethane to lost circulation zones will be developed. This involves a number of choices: should one-part or two-part polyurethane be used, should the material be tripped in a canister or be pumped in, should canisters be reusable or disposable/drillable, etc? Industry input is being sought to guide such choices. Testing of some components, inflatable packers, check valves, etc., has begun as the first step in developing emplacement schemes. Once experience is gained with emplacement techniques in the lab, field demonstrations will be conducted.

**Conclusions**

The development of polyurethane foam as a chemical grout for lost circulation zones and borehole stabilization is progressing. There is no longer a question of whether polyurethane can be formulated for geothermal temperatures. Work being done on controlling the process and understanding how polyurethane chemistry effects proper plug formation has reached a point where development of emplacement techniques can begin. Polyurethane grouting is being regularly applied to create grout curtains and seal boreholes in dam remediation and mines demonstrating its applicability to solving lost circulation problems. Sandia is seeking opportunities to test the application of polyurethane to lost circulation zones in geothermal drilling projects. Prime targets would be near the surface (≤1000 ft.), close to or above the water table.

**Acknowledgements**

The contributions to this work of Earl Doyle, Polyurethane Consultant, Houston TX are gratefully acknowledged. Without his help, the project would have undoubtedly repeated past mistakes. IPI International Inc. and Green Mountain International Inc. are gratefully acknowledged for their support providing materials to test and advice.

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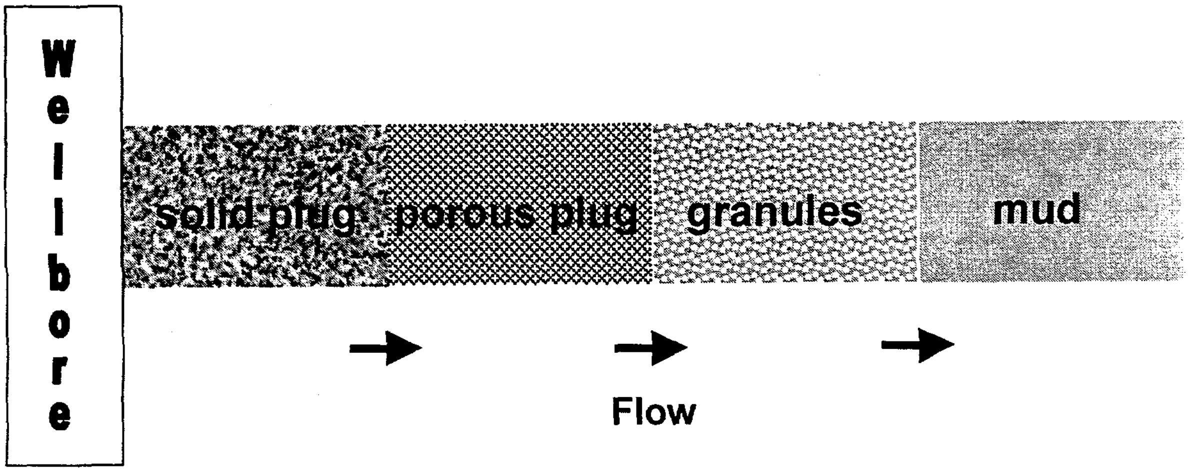


Figure 1: As the polyurethane sweeps out the mud there is a transition from polyurethane granules dispersed in the mud, to porous polyurethane, and finally a hard solid plug of polyurethane.

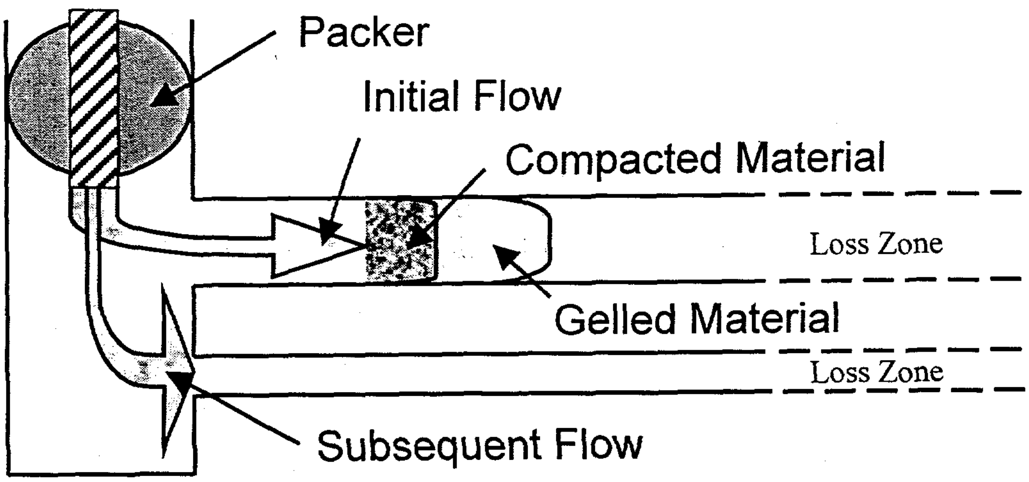


Figure 2: Effect of polyurethane gelling on injection process.

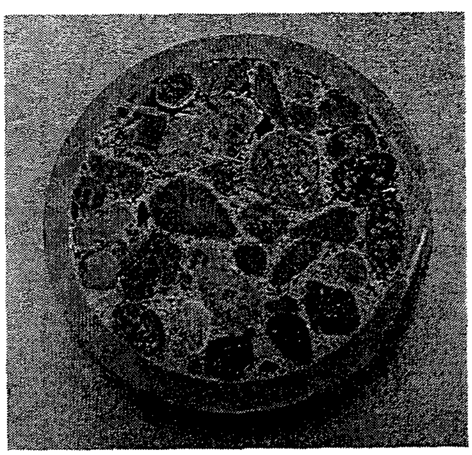

Figure 3: Leakage channels resulting from injecting inadequate polyurethane for less that the gel or set time.