New developments for State-of-the-Art Crane Rectifier Application

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INTRODUCTION

Currently, there is a large installed capacity of rectifiers for cranes. The old technology of these rectifiers, works either with a diode rectifier or an SCR phase control rectifier, and both of them burn the regeneration energy on a resistor which is activated via a dynamic brake contactor. The diode technology obligates to use a dynamic brake contactor and a resistor to dissipate the regenerative energy. The old SCR rectifiers operates with a really low AC voltage, which even though it may have a regenerative SCR bridge, reduces the possibility of regeneration by other methods rather than using a dynamic brake contactor and resistor. This technology present voltage regulation, voltage spikes, energy loss and diagnostic issues.

New developments with the ability for energy saving using a regenerative power bridge using the same voltage levels as the older technologies, arc flash protection and an enhance ground fault protection, gives a better cost vs benefit solution to the customer. These new features allow a flaw-less operation with better diagnostics, saving a substantial maintenance cost.

DISCUSSION

Problem description

The old rectifiers work with a AC/DC Voltage ratio about 0.80, which do not allow regeneration by using reverse bridge. These issues force the rectifier to use a dynamic brake contactor and a resistor to dissipate the regenerative energy. The dynamic brake contactor close and open with load which causes wear on the contacts which causes a maintenance cost. Also, this energy that is dissipated on the resistor may be used by other equipment on the line.

The poor diagnostics of the old rectifiers make them hard to troubleshoot. The information given is not enough and the downtime caused by this issues is significantly enough to stop a production line for a long time.

ANALYSIS

Overall problem definition
The main driver is to reduce downtimes by reducing the troubleshooting time, save energy, and get rid of the equipment that suffers of wear. To give a solution to this problem, it is need to design aa regenerative rectifier that operates at a AC/DC voltage ratio between 0.80-0.85 that has the possibility to send the regenerative power back to the line.

- Dynamic Brake Contactor wear.
- Regenerative energy dissipated on resistor.
- Low voltage AC level to use a regenerative bridge.
- Poor diagnostics.

Dynamic Brake Contactor wear, Regenerative energy dissipated on resistor, Low AC Voltage level to use a regenerative bridge.

REGENERATIVE ENERGY DISSIPATED ON RESISTOR. - The most common solution to control the regenerative energy is using dynamic brake contactor with a resistor. This solution has some weak points such as the response time and the wear caused by closing and opening the contactor with load. Also, the resistor is heated every time the contactor is closed, leading to a future failure where the resistor breaks to an open circuit where no regenerative energy will be dissipated causing an overvoltage on the circuit which can damage other parts of the circuits of the cranes or cause a flashover on the motor's commutator. One way to avoid this is to over dimension the resistors so they can handle more power than what they should.

The dynamic brake contactor has a life cycle where if it is overlap the contactor will fail by not closing the circuit anymore, leading to the same results described on the last paragraph. The maintenance team should check the contacts as a preventive maintenance, which leads to a higher maintenance cost. This solution is shown on Fig. (1).

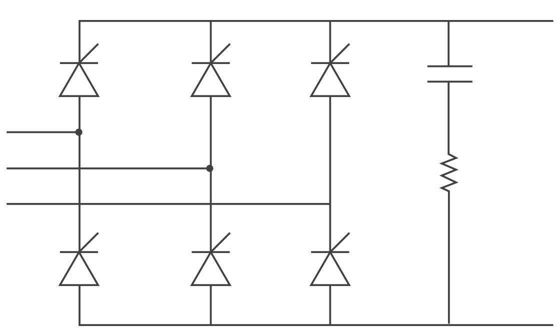

Fig. (1) Bridge/Dynamic Brake Contactor + Resistor Single

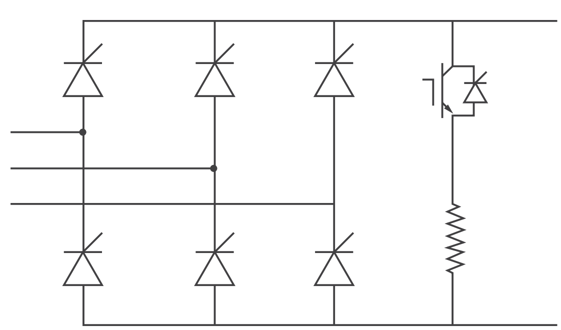

Fig. (2) Bridge/Chopper + Resistor Single Line

There are other solutions in the market where a DC/DC chopper is used to regulate the excess of voltage dissipating the energy on a resistor. The chopper has a faster response time than a dynamic brake contactor, but it still burns the energy on a resistor. This solution is shown on Fig. (2).

LOW AC VOLTAGE LEVEL TO USE A REGENERATIVE BRIDGE. -The three problems are related to one another. It is really difficult to regenerate using a power SCR bridge due to the AC voltage / Voltage Ratio. When the AC voltage has a low level, the commutation voltage is not enough. This causes that the overlap angle increase to the point where $\beta - \mu = \gamma < 0$. At this point the commutation failure is imminent and this will take the rectifier to a diametrical fault. This kind of faults lead to open fuses or shorted SCRs.

Some authors suggest that a rectifier should stand voltage dip of 10% to regenerate, and the safe DC voltage level to work as an inverter, depends on the load, the commutating angle and the impedance of the reactance before the rectifier. There is an inverse relationship between the safe DC voltage level to regenerate and the impedance and load. The higher the load, or higher the reactance the lower safe DC safe voltage level to regenerate. Some authors suggest that 0.5 PU of regeneration current, the voltage ratio DC voltage / AC voltage should be around 0.87%. This is not the case of a rectifier for cranes when usually the voltage ratio is 0.85 or lower. Using a standard SCR rectifier, compromises the regeneration process by highly potentiating the risk of a commutation fault on the bridge. This process may continue with a diametrical fault. Fig. (3) shows the behavior of commutation fault.

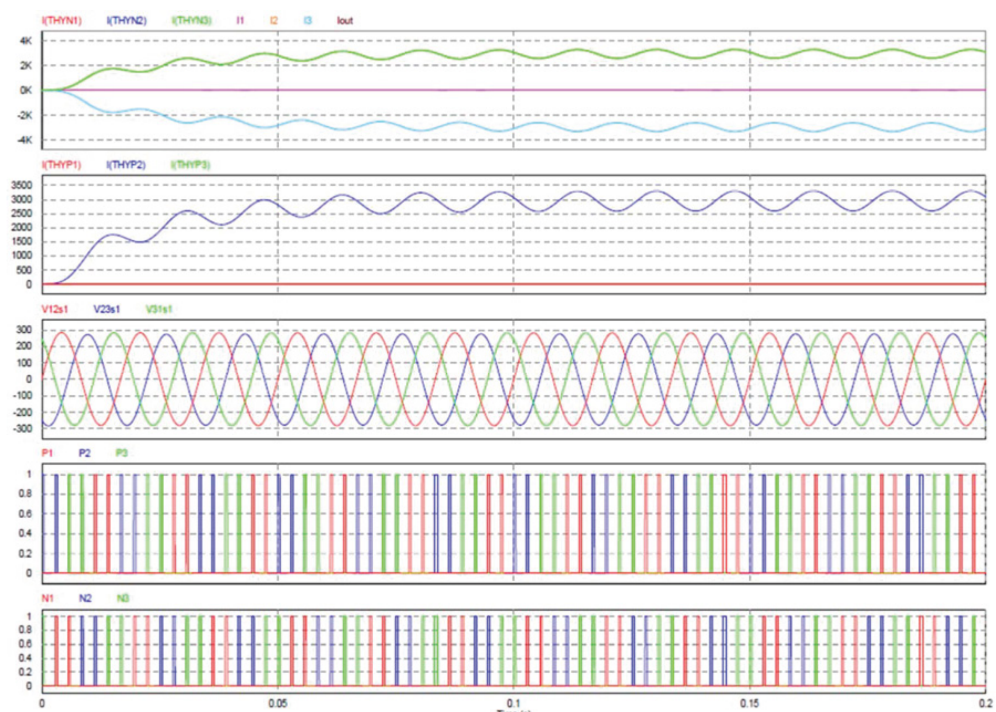

Fig.(3) Commutation Failure

Poor Diagnostics and Troubleshooting

The older rectifiers have no friendly diagnostic features. Most of the time only the DC and AC breakers trips, giving no information of what was the cause of the failure. These leads the maintenance team to check the complete rectifier, SCR per SCR, or even though checking the crane motors looking for grounding points, to troubleshoot the equipment causing an increase of maintenance cost.

The newest rectifiers, has keypads where some failure information is displayed, but does not give further information that can help either to a preventive or corrective maintenance or give the exact point of failure.

SOLUTIONS PROPOSED

The problem is summed up into designing a power rectifier which minimize the mechanical moving parts during operation, decrease the parts that are heated during operation and that provides enough trouble shooting information that minimizes downtime in case of failure.

REGENERATIVE SOLUTION. - Usually the existent transformers will give a AC/DC voltage ratio about 08.-0.85. The main solution comes by maintain the overlap angle as minimum as possible. The behavior of the overlap angle obeys to the next equation.

$$\frac{XI_d}{E} = \cos(\beta - \mu) - \cos(\beta)$$

Where X is the reactance of the system, which varies depending on the number of motors that are activated, I_d is the current on the rectifier, *E* is the voltage, β is the retard inverting angle, and μ is the overlap angle. Reducing the overlap angle decrease the possibility that *y*is less than 0.

$$\beta - \mu = y$$

Since the reactance varies, but it will never be less than the reactance of the transformer, and the voltage is a value that is fixed by the existent transformer, leads to take the I_d current to zero. In other words, commutate the SCRs without current.

$$\frac{XI_d}{E} = 0 = \cos(\beta - \mu) - \cos(\beta)$$

$$\cos(\beta - \mu) = \cos(\beta)$$

$$\mu = 0$$

To achieve this, the next circuit is proposed:

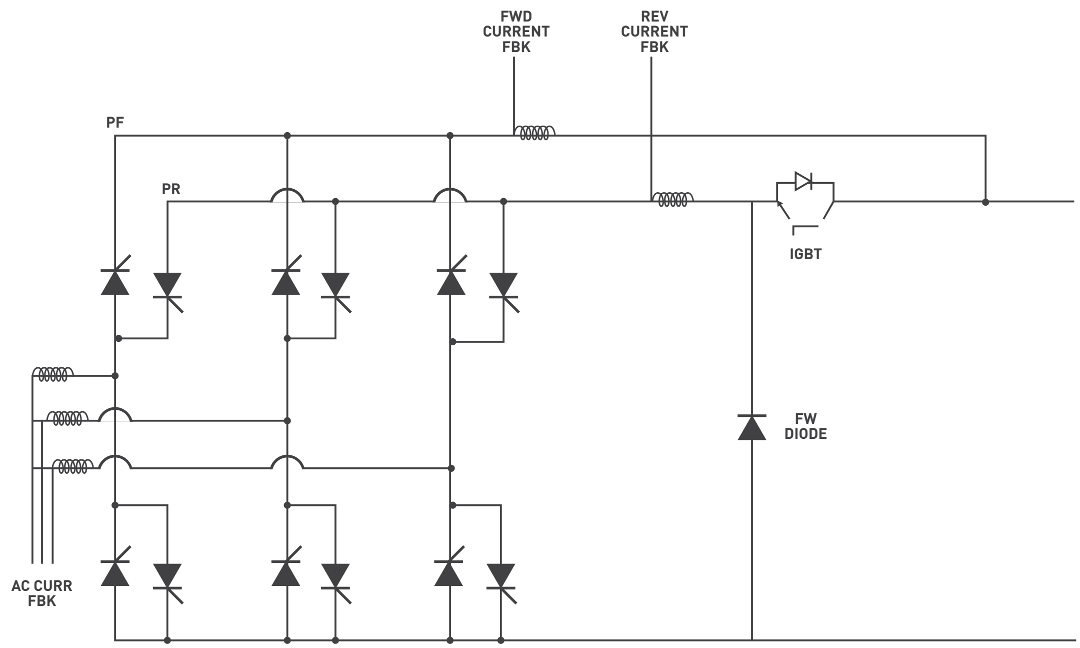

Fig. (4) Regenerative Power Bridge

The IGBT will open the circuit open the circuit just before the SCRs are fired to commutate. The IGBT will stop the current flow, just before the SCRs are fired. While the circuit is open the SCRs will be fired by burst firing signal, then the SCRs, then the IGBT will close the circuit again. This way the SCRs are commutated without current.

The behavior of the regenerative circuit is shown on Fig. (5) and Fig. (6).

The IGBT stops conducting every time a pair of SCR is going to commutate. Notice the behavior of the current. Every time the SCRs commutate, the current drops. This happen because the IGBT opens the circuit, leading to commutate the SCRs without current, giving safe conditions to avoid any kind of commutation faults. This concept leads to avoid commutation failures during regeneration. Commutation failures comes after the first pair of SCRs commutate. The first pair will commutate without problems, but the next pair will fail when the SCR does not stop conducting because of a low commutation voltage. This circuit, guarantees that the SCRs will commutate under the same situation as first SCRs.

Every time the lock out logic sends the firing signal for a pair of SCRs, the processor will stop firing IGBT while holding the firing signal to the SCRs. The mail control monitors the regenerative current waiting until the moment that is totally extinguish. After the reverse current extinguish, a safety pull up timer (20us) starts running. When both conditions, zero regenerating current, and the safety time coexist, the IGBT and the firing signals are enabled. This process is shown on Fig. (7). The firing signals for the SCRs is a 15 degrees burst firing signal.

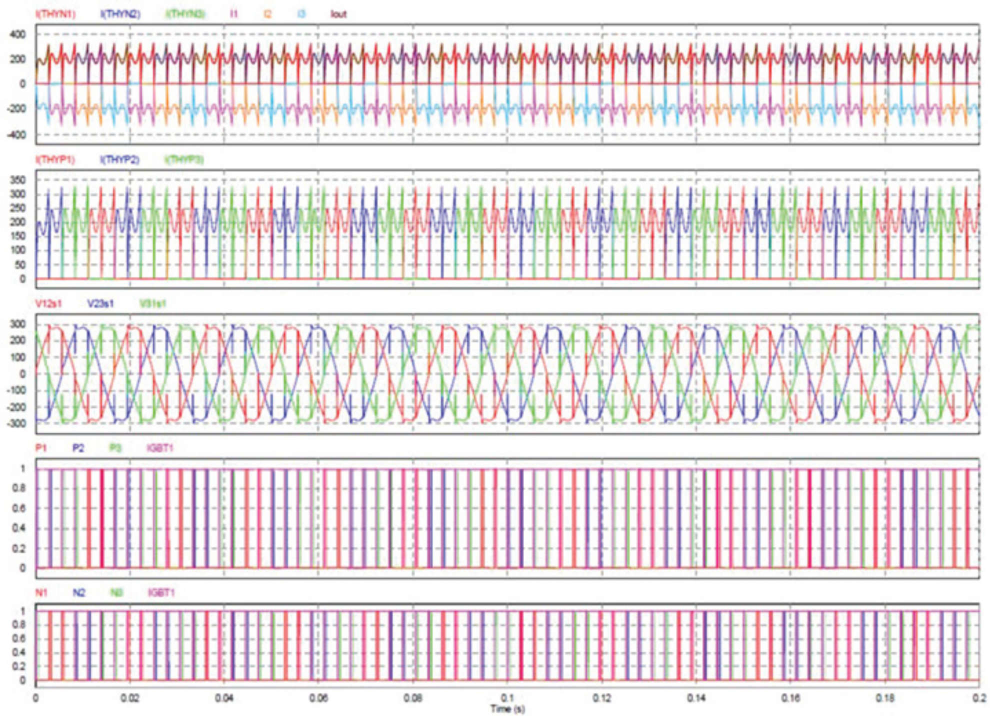

Fig. (5) Simulation.

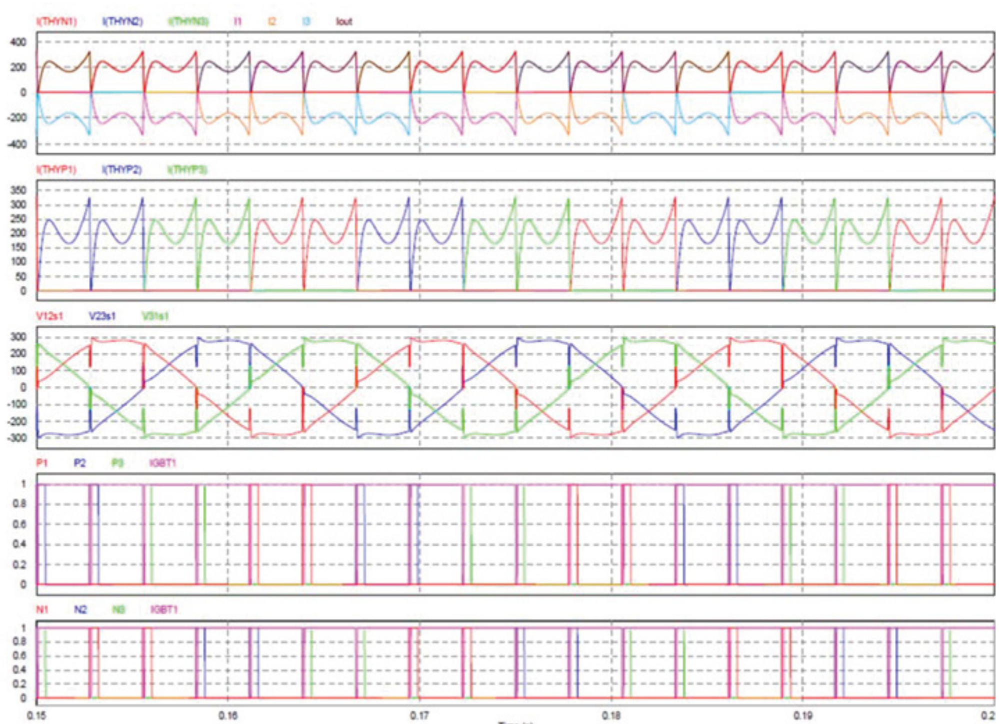

Fig. (6) Simulation.

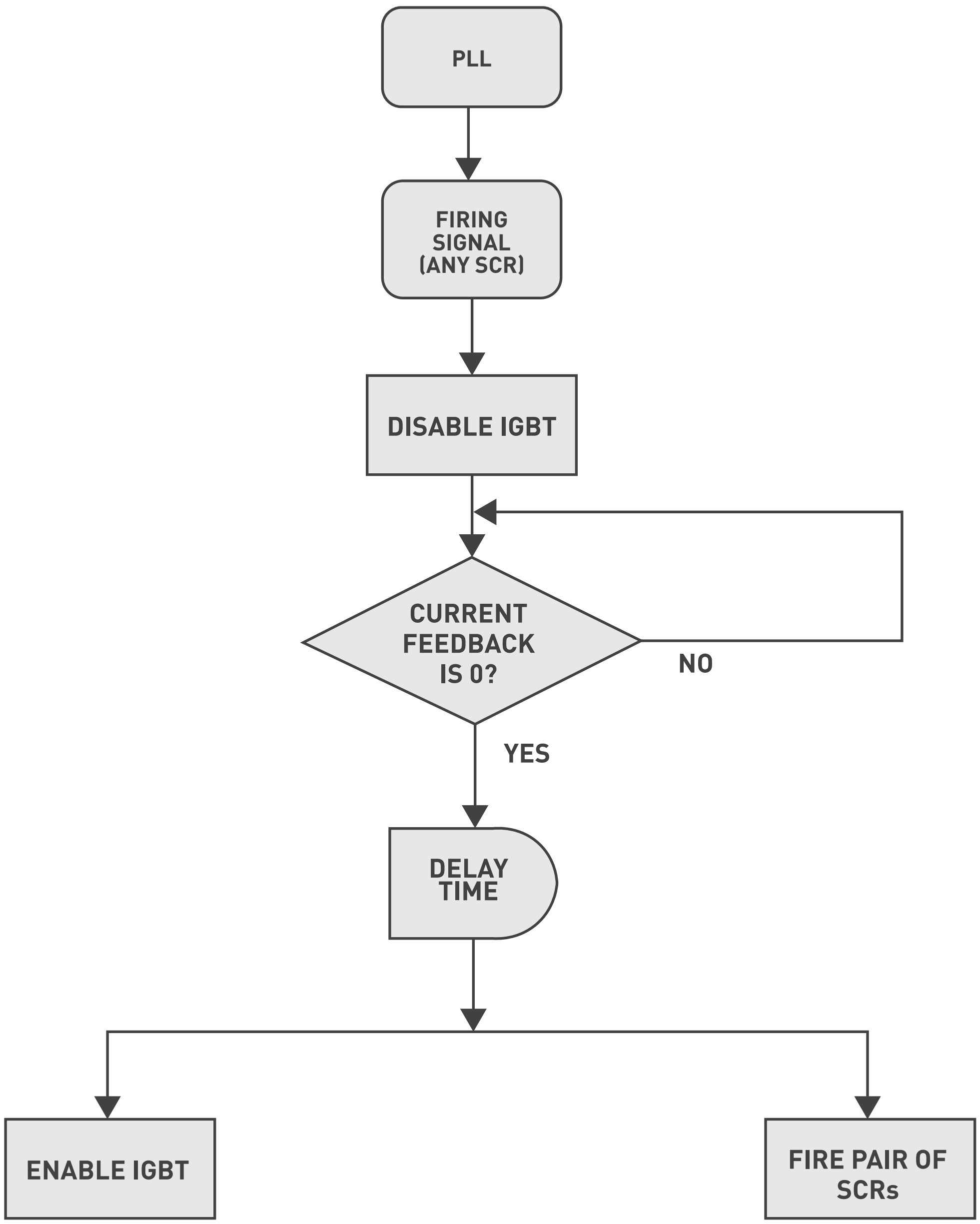

Fig. (7) IGBT and SCRs firing process

Enhanced Diagnostics

Even though a crane rectifier is not the equipment which will be connected to a production industrial network, using a keypad with enhance diagnostics gives the maintenance equipment the facility for a trouble shooting situation, with the objective of increasing the availability of the equipment. Fig. (8) shows a single line diagram of the complete system.

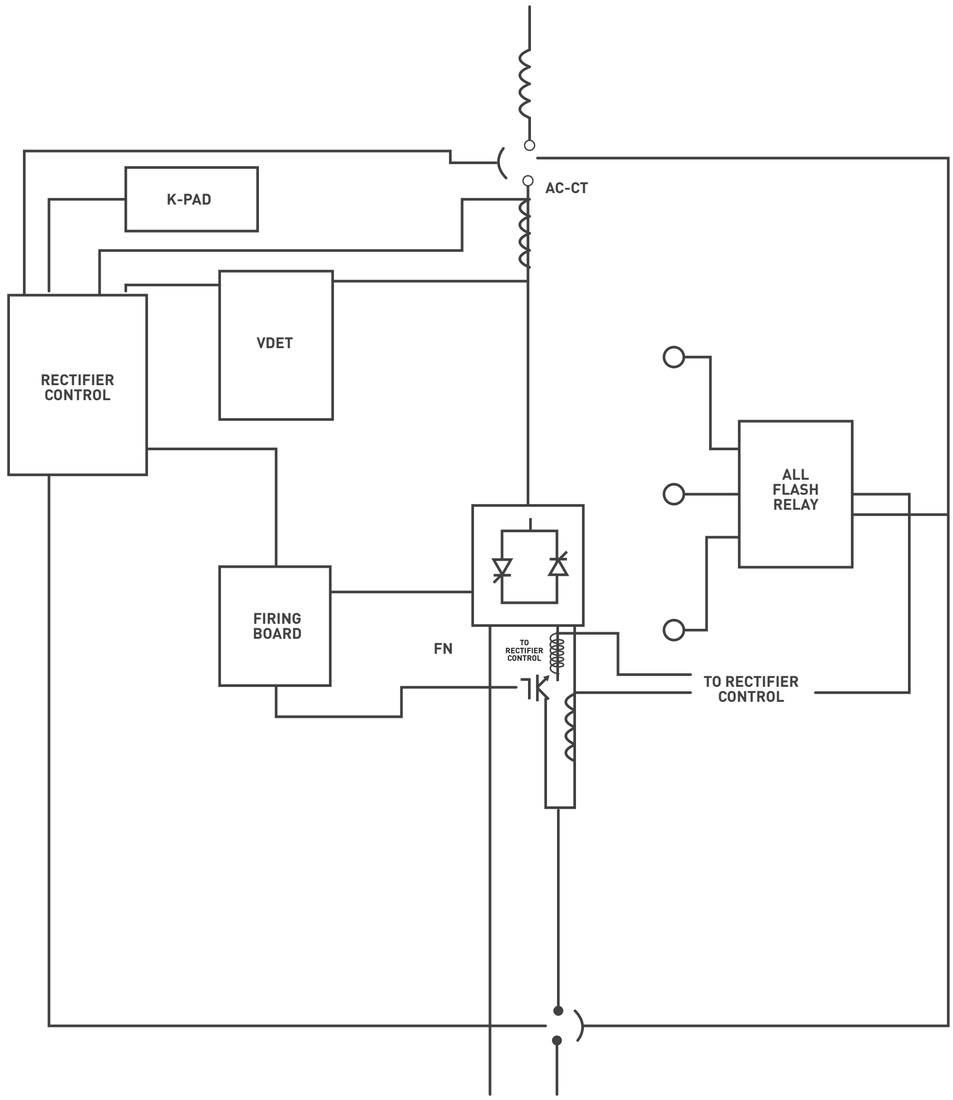

Fig. (8) Single line control diagram

The keypad shows the actual DC Voltage and DC current, 5 minutes RMS load, 40 minutes RMS load, energy supplied from the rectifier and the energy that has been saved by regenerating back to the line.

The controls will be able to take action over faults like AC overcurrent, DC overcurrent, DC overvoltage, PLL errors, overload. Also this new design contemplates an Arc Flash Relay that is backed up with a high speed AC over current fault detection, which opens the AC incoming and DC output breakers through high speed solid states relays, isolating the equipment and avoiding catastrophic damage inside the rectifier as well as outside.

The ground detection has two different designs, depending if the transformer secondary is grounded or not.

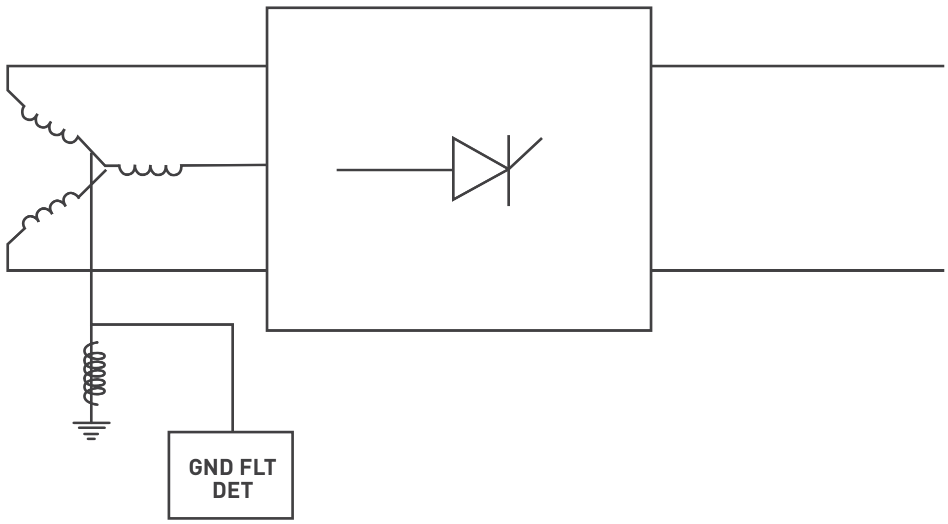

Fig. (9) Ground Fault Detection System for floated systems

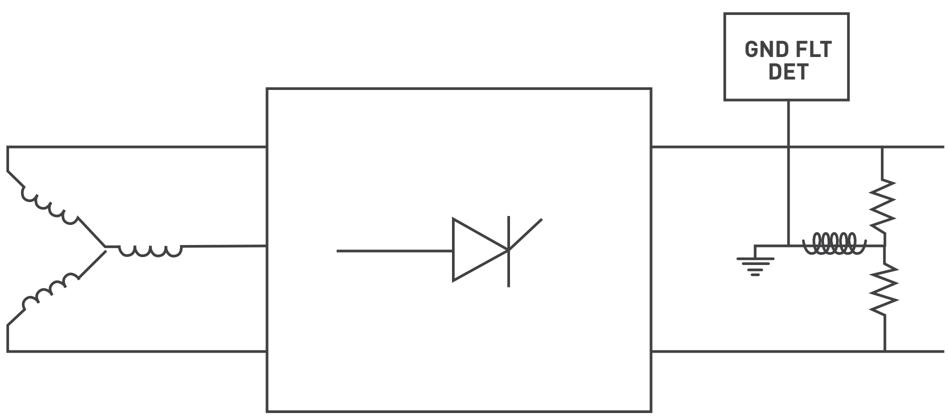

Fig. (10) Ground fault for grounded systems

***Note: The Ground detection fault for grounded transformer secondary has been used in different systems before. The results where minimizing downtime and avoiding catastrophic failures where the arc flash on the rails of the crane caused damaged equipment and in personnel from the plant.

The new design contemplates a cell test to verify the status of the SCRs. When using a multibridge, the cell test is performed to each bridge separately. Since there is no load on the rectifier, the control fires at a fix firing angle, and the diagnostic features compare the 6 pulses voltage wave forms during two cycles expecting to have the same amount of voltage on each pulse.

In case it appears voltage in one of the pulses before the firing signal the control will recognize it as a shorted SCR. In case on pulse is missing the control will recognize it as an open SCR. This information appears on the keypad giving the maintenance team better trouble shooting information, maintaining the equipment availability.

CONCLUSIONS

Even the simplest application as a crane rectifier can cause energy losses and may have a considerable maintenance cost. This new concept intends to take this kind of rectifiers to a new generation. The benefits of this concept, can be measured on higher availability of the equipment, maintenance costs and reducing energy costs. The new features such as enhance diagnostics allows the user to minimize downtime and maintenance costs. The redundant arc flash protection, is designed to reduce the risk of an incident and to protect the personnel around the rectifier. The regeneration capabilities are intended to make this rectifier an environmental friendly equipment by recovering the energy of the motors when there are regenerating, and send it back to the line.

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