Development of VAR / P.F Regulator for Brushless A.C Generator for Paralleling with Grid

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Abstract:* The main objective is Paralleling Brushless A.C. Generator to Grid system in constant VAR or in PF mode. Presently, the trend is to feed power to Grid from different sources of potential heads. That is available in different valley regions in India for meeting the power demand. Hence, the question of feeding power to national Grid. Power generated from different mini and micro Hydel projects are fed to grid in meeting the above demand. Based on Stiff Bus concept any power feeding to Grid will not be stable. Since, the power bus from Grid is stiff in Nature. To make the Generator adoptable to parallel with Grid we need a regulator to work either in Constant VAR or Constant PF mode .So that the Generator Rotor is not over loaded under any circumstances throughout power flow pattern to Grid. To meet the above a Regulator of PF/VAR control is added to the existing AVR. So, that the excitation according to set p.f or VAR get adjustable. So, that the Generator Rotor is protected throughout.

KEY WORD: AVR, Brushless A.C Generator, Grid, VAR / p.f regulator

1. INTRODUCTION

The use of VAR/p.f. regulators and controllers has their origins in industrial applications of synchronous motors and generators, in which the synchronous machine is typically tied directly to a plant distribution bus. In many of these industrial applications, the machine voltage is expected to follow any variations in the utility-fed system voltage, in which case machine voltage regulation may not be desirable. VAR/p.f. regulators and controllers are often used in these types of industrial applications.

During periods of peak system load, many areas are prone to voltage stability problems, in which voltage on the heavily loaded system can slowly decay and collapse, unless proper reactive power support is provided. Also, analysis of events leading to recent power blackouts in the western United States has shown that the system problems were at least partially related to the lack of reactive power support from a number of generators on the system. In such situations, it is important that all available generating stations provide the needed increases in excitation level that only a properly functioning voltage regulator can provide ,uninhibited by any automatic VAR or p.f. controller.

Modes of Generator operation:

AC Generators are operated in following modes depending on power demand by the system.

1. Solo running (independent running)
2. Parallel running among generators
3. Parallel running with grid

1. Solo running: in solo operation the generator is feeding independent load. Hence, the load is single source dependent. Any breakdown will halt the complete system. Solo running diesel generator sets are not suitable for feeding critical loads without a stand by source as electricity board supply.

Hence the diesel generator set operation in solo mode is suitable for non critical loads only. Features available in solo running sets are self regulated voltage according to class of voltage regulation regulated voltage variation to the extent of ±5% smooth voltage build up and provision for remote voltage control.

Limitations:

- Single dependent source
- Total interruption during fault
- No loads sharing since it is a single source
- Paralleling to grid is not stable because of restricted automatic voltage regulator operating zone

2. Parallel running among generators:

The necessary conditions for the parallel operation are

- Correct phase sequence.
- Voltages in phase.
- Frequencies should be equal.
- Voltage should be equal.
- Loads shared by each of the generator should be proportional to its rating.

For ensuring reliable power supply, the power demand is met by connecting multiple sources on common bus so, that the critical loads are always fed from any one source for ensuring the reliability of the power system.

Parallel running of diesel generator sets will share the loads according to power demand. For qualifying the voltage regulator suitable for paralleling, the following features are to be built in voltage regulator.

Current compensated adjustable quadrature droop compensation for equal kvar sharing.

- Voltage trimming facility to the extent of ±10% for initial adjustment after paralleling to ensure equal KVAR sharing among generators.
- Change over facility to change mode from solo to parallel after droop set in solo mode.

For ensuring stable parallel operation, in addition to quadrature droop compensation, engine speed droop are to be similar among prime movers for equal KW sharing. However equal sharing is for ideal condition. Hence variation to the extent of ±10% for KW and KVAR sharing is acceptable in practice.

3. Paralleling of generators with grid:

When a generator is to be paralleled with the Supply Utility Grid the voltages on either side of the paralleling circuit breaker must be matched (synchronized). To synchronize the generator set and the Grid voltages, three different parameters of the generator set voltage across the open paralleling circuit breaker must be controlled.

- The voltage magnitudes: For safe paralleling, a maximum voltage magnitude difference of 0.5 percent is recommended.
- The frequency of the voltages: For safe paralleling, a maximum frequency difference of 0.1Hz is recommended.

The phase angle between the voltages: For safe paralleling, a maximum phase angle difference of 10 degree is recommended.

When a machine operates in parallel with a power system, the voltage and frequency will be fixed by the system. The voltage regulator no longer controls the generator output voltage. The fuel supply to the prime mover which is controlled by the governor determines the power which is supplied by the generator. The generator excitation determines the internal Electro motive force of the machine and therefore affects the power factor.

For effective utilization of waste heat energy, in private thermal plants like sugar industries generate their own power since fuel generated from raw material, during power generation the plant will produce waste steam after generation. For better utilization of steam, power generation is second level by is planned by utilizing waste steam. The power so generated is fed to grid for converting as company revenue since the same is excess. The generation like this can be done in multiple levels for effective utility of steam and fuel and the same exported.

Mini and micro Hydel projects in India are exporting power to grid as external support to meet power demand. Following features are added to the normal voltage regulator for safeguarding incoming generator to grid.

- Automatic power factor control
- Minimum excitation limiter
- Maximum excitation limiter
- Stator current limiter

Grid is a power bus with infinite capacity since they are supported by multiple units (Generator) of huge capacity compared to the capacity of incoming generator used in mini and micro Hydel project. Power generation in small capacity for export purposes are not suitable for feeding to grid with normal automatic voltage regulator since the change in excitation of incoming generator will not alter the grid voltage. Hence results in changing KVAR supplied to grid in turn results in power factor change. This process is cumulative if KVAR supplied to grid is not controlled. Hence there is need for intelligence to detect this situation. Addition of automatic power factor control unit to the existing automatic voltage regulator will build the required intelligence in the above situation. Hence need of VAR/p.f. regulator is highly essential. After paralleling the control is automatic. Hence control is unmanned. This feature is essential only for paralleling with grid.

System block diagram

The system block diagram of our proposed project is as shown below. It consists of AC brushless generator, Grid, automatic voltage regulator and VAR/p.f. regulator rotating part of AC brushless generator includes exciter output, rotating rectifier assembly and main rotor.

Initially synchronization process must be carried. When generator terminal voltage is equal to grid voltage the power factor will be unity and VAR reads zero. When the generator terminal voltage is less than grid terminal voltage then the VAR reading will increase in the Leading direction, and the power factor will decrease (be less than 1.0) in the Leading direction. Leading VAR and pf are usually considered to be negative. If the generator terminal voltage is greater than the grid voltage the VAR reading will increase in the Lagging direction, and the power factor will decrease (be less than 1.0) in the Lagging direction. Lagging VAR and p.f. are usually considered to be positive. The signal obtained from the VAR/p.f. regulator is superimposed on AVR corresponding to positive compensation it will buck the AVR voltage and for negative compensation it will boost AVR voltage overall for buck & boost process

Voltage gain of the system will change.

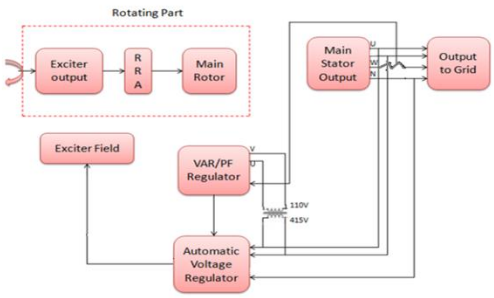

Fig.1.1.Block diagram of proposed project work

From the above it is very clear that the generator is protected while feeding grid when the automatic voltage regulator system is supported by VAR/p.f. regulator. The system will monitor either in constant pf mode or in constant var mode according to mode selection.

In addition to VAR/p.f. regulator, minimum or maximum excitation limiter and stator current limiters is used as backup in case of VAR/p.f. failure for ensuring positive protection. These features are optional depends on reliability of VAR/p.f. regulator operation.

Functional aspects of VAR/p.f. regulator

VAR/p.f. regulator works on principle of vector addition of Icosϕ and Isinϕ. To do so, we have to segregate Icosϕ and Isinϕ component from current source. The required current is derived from secondary of current transformer in one phase as input for comparing with voltage source from two lines other than the one used for deriving current through potential transformer. The current and voltage sources are compared for phase angle and fed to comparator for deriving output proportional phase angle between voltage and current.

The output is direction sensitive for discriminating pf lead or lag for taking care of correction appropriately. For achieving the pf setting as desired between 0.8 lag to 0.8 lead, provision is made for changing the pf setting to attain pf setting as desired.

1.2 Objective of paper

The main objective of this paper is to developing a device for Paralleling A.C Generator to Grid system. When a synchronous generator is parallel operating with a stiff bus, it is bound to vary its reactive current since bus voltage is uncontrolled.

Hence any voltage variation on grid results in varying var supplied to bus in the above situation. Hence changing var on its own is cumulative unless suitable control is exercised. For achieving the same we need to add Var/p.f regulator as add on feature to the existing AVR. To have various options the regulator shall operate either in constant var or constant pf mode.

2. METHODOLOGY

Study on automatic voltage regulator control scheme for

- Stuffing printed circuit board as per the identification of components on printed circuit board (PCB).
- Static test for circuit function.
- Access control point in automatic voltage regulator for superimposing the control signal for correction.
- Implementation on automatic voltage regulator system and effect of superimposing the signal on automatic voltage regulator (AVR).
  The following above steps can be explained below:
- Stuffing printed circuit board as per the identification of components on printed circuit board (PCB).
  - Study the schematic and identify various components used.
  - Identify the components legend wise on printed circuit board (PCB) as shown in Fig. below.
  - Insert components on printed circuit board as per the legend on PCB as shown in Fig. below.
  - Solder components on printed circuit board as shown in Fig. below.
  - Apply protective coating on soldered area of printed circuit board.
- Static test for circuit function.
  The developed device can be tested alone without using machine (by manually) is known as static test.
  Wave form observed at terminal block 1(TB1).

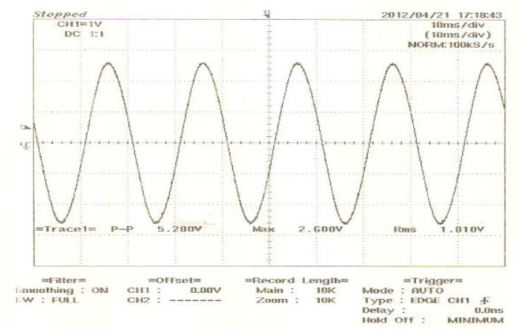

Fig.2.4

Wave form observed at terminal block 3(TB3).

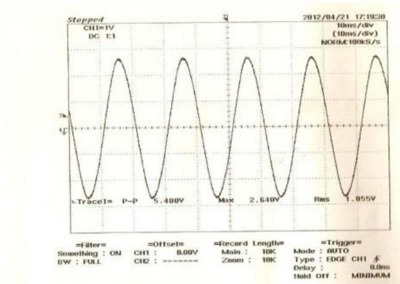

Fig.2.5

Waveform observed at pin number 8 of IC1 CD 4016.

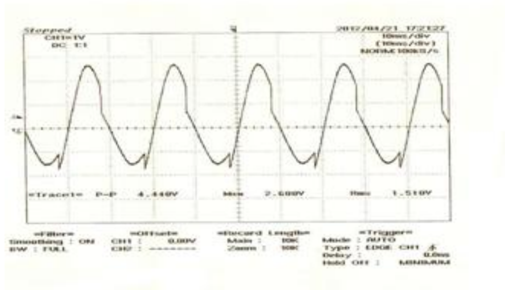

Fig.2.6

Wave form observed at test point 9, test point 10 and testing point 12:

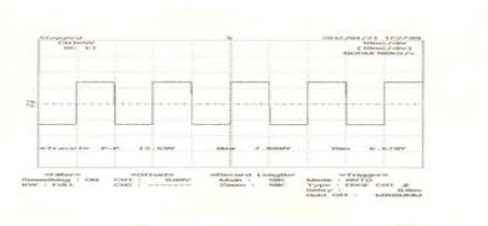

Fig.2.7

- Implementation on automatic voltage regulator system and effect of superimposing the signal on automatic voltage regulator (AVR).

VAR/p.f. regulator output connected to sensing point of AVR and found voltage change in generator output. Hence results in constant p.f. Mode operation for variable load condition.

3. SYSTEM DESIGN

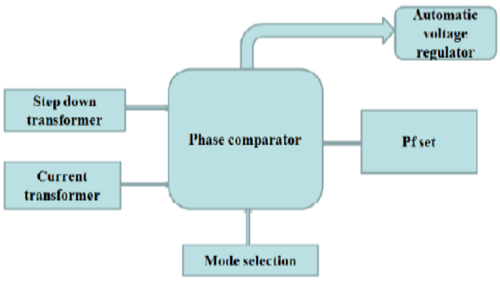

Fig. 3.1: Block diagram of VAR/p.f. regulator.

Step down transformer

A step-down transformer is one whose secondary voltage is less than its primary voltage. It is designed to reduce the voltage from the primary winding to the secondary winding. This kind of transformer "steps down" the voltage applied to it. They are commonly used to convert 220V to 110V.As a step-down unit, the transformer converts high-voltage, low-current power into low-voltage, high-current power. The larger-gauge wire used in the secondary winding is necessary due to the increase in current. The primary winding, which doesn't have to conduct as much current, may be made of smaller-gauge wire.

Current transformer

A current transformer is defined as an instrument transformer in which the secondary current is substantially proportional to the primary current (under normal conditions of operation) and differs in phase from it by an angle which is approximately zero for an appropriate direction of the connections. This highlights the accuracy requirement of the current transformer but also important is the isolating function, which means no matter what the system voltage the secondary circuit need to be insulated only for a low voltage.

The current transformer works on the principle of variable flux. In the "ideal" current transformer, secondary current would be exactly equal (when multiplied by the turns ratio) and opposite of the primary current.

A current transformer can function in:

- metering of power to track energy use
- monitoring of current flow through a circuit
- relay of power through an energy grid
- control of the state of a circuit (open or closed) in a ground fault circuit interrupter
- protection of instruments and appliances connected to AC power supplies.

Phase comparator:

A phase detector or phase comparator is a frequency mixer, analog multiplier or logic circuit that generates a voltage signal which represents the difference in phase between two signal inputs.

The phase detector needs to compute the phase difference of its two input signals. Let α be the phase of the first input and β be the phase of the second. The actual input signals to the phase detector, however, are not α and β, but rather sinusoids such as sin (α) and cos (β).

In general, computing the phase difference would involve computing the arcsine and arccosine of each normalized input (to get an ever increasing phase) and doing a subtraction. Such an analog calculation is difficult. Fortunately, the calculation can be simplified by using some approximations.

Mode selection

Select constant p.f. mode or constant VAR mode according to our use.

The complete module consists of power supply to feed op-amps and gate circuits. The module is provided with phase comparator where in the phase angle between current and voltage is compared with respect to the set power factor and the correction is applied between -5v to +5v till set power factor is attained.

The above output signal is sensed by AVR and starts correcting the excitation till the set power factor is attained.VAR/p.f. regulation is the feature built into act either mode in case of constant var mode power factor is governed to maintain the constant VAR. In case of constant p.f. mode control VAR is governed to maintain the set power factor.

This unit is switched only when generator parallel to grid to ensure this provision is made to interlock with grid circuit breaker also in independent control for switching the regulator irrespective of interlock is provided as master control. The module is fed with source voltage from u & v phases which are fed through transformer for feeding the designed voltage.

Basically in VAR/p.f. regulator circuit diagram we have two signals are voltage signal and current signal.

In voltage signal 415v is the generator voltage step-downs to 110v this 110v is again step-downs to 18v the regulated dc power supply circuit consists of full wave bridge rectifier circuit operates in pair to gives a voltage 0f +24v to -24v that voltage is dropped to 7.5v by the use of dropping resistor connected in series between the terminals of Test Point 3 and Test Point 5 the +7.5v and -7.5v is unregulated power supply that is given to Zener diode to provide the regulated voltage of +6.5v for the operation of op-amp circuit.

In current signal the current transformer output is dropped across capacitor for discrimination of Isinϕ and Icosϕ. The output of the current transformer is connected with respect to ground for serving input to quad static switch the static switch is triggered with the help of level comparator driven by sine wave to get the square wave output.

The output of the quad switch under the control of zero crossing detector segregates IsinΦ and Icosϕ components the output so generated is fed through op-amp for avoiding loading of the switch. The output of the op-amp is fed to converter for converting the current signal in to DC varying voltage level from positive to negative with respect to ground. The output of the converter drives transistorized switch from positive to negative with respect to ground According to the base current received by the transistor. The current drive to the transistor is totally dependent on VAR/p.f. set which the limiting point for correction is on to stop. Hence VAR/p.f. is regulated.

Advantages of VAR/p.f. regulator:

- Consistent power factor under fluctuating load conditions.
- Reduced KVA demand charges.
- This unit in association with var limiters one can ensure that the system will not demand negative excitation.

4. EXPERIMENTAL SET UP FOR VARYING THE POWER FACTOR:

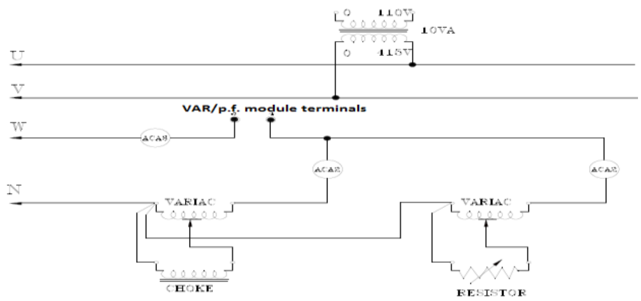

Fig.4.1

Procedure for Conducting Simulation Test:

1. Connect current transformer output to terminal block 1, terminal block 2 & terminal block 3.
2. Adjust load till current in ACA3 till 1Ampere through dimmer-1 & dimmer- 2
3. Connect voltage source of 110v through potential transformer from u & v phases.
4. Measured voltages at test points as shown in table

Sl. No.	Parameter	specification	Calculated value
1	Voltage at TP3	21.6V to 26.4V	24.26V
2	Voltage at TP4	-21.6V to -26.4V	-24.26V
3	Voltage at TP2	0	0
4	Voltage at TP5	6.75V to 8.25V	7.6V
5	Voltage at TP6	6.12V to 7.48V	6.96V
6	Voltage at TP7	-6.12V to -7.48V	-6.56V
7	Voltage at TP8	6.75V to 8.25V	-7.27V
8	Voltage at TP9	Amplitude of waveforms 6V to 7.5V	
9	Voltage at TP10		
10	Voltage at TP11		
11	Voltage at TP12		

Table 4.1

Wave form observed at Test Point 9 and Test point 11:

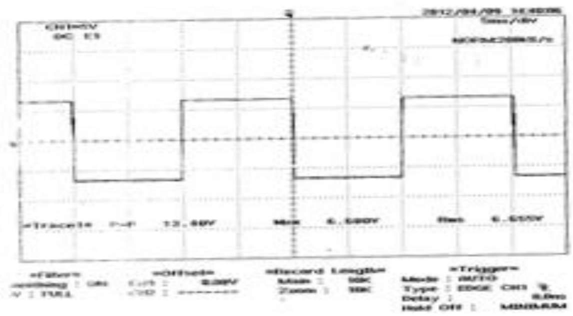

Fig 4.2

Wave form observed at Test Point 10 and Test point 12:

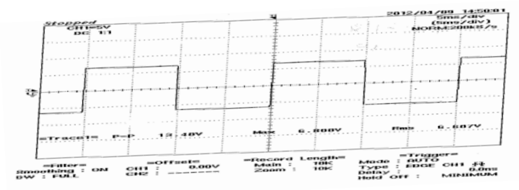

Fig 4.3

5. Connect 5kΩ VAR/p.f. pot to Terminal block 10 and terminal block 19 and Terminal block 20.

6. Observe wave form at test point 13.

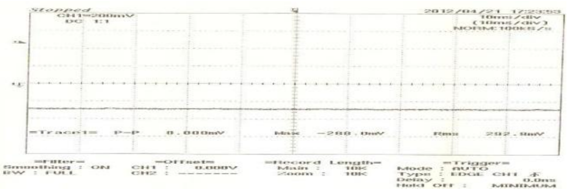

Fig.4.4

7. Observe wave form at test point 14.

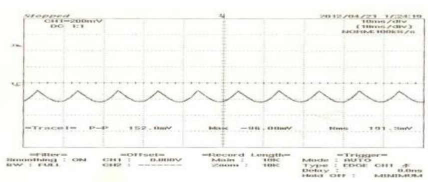

Fig.4.5

8. Vary power factor var/pf set pot and check for variation of output at TB18 and TB 19 between positive to negative.

Test of var/pf regulator module with current transformer output simulated using single phase variable voltage source.

1. Set the following current as shown below:
Initially the value of Icosϕ and Isinϕ has to be set by manually in ACA-1and ACA-2.
And we can see the corresponding values of current in ACA-3.

ACA-3	ACA-1(Icosϕ)	ACA-2(Isinϕ)
1	0.8	0.6
0.8	0.64	0.48
0.6	0.48	0.36
0.4	0.32	0.24

Table.4.1

Calculation for 1Acurrent:

Power factor (cosϕ)=0.8,$\phi=\cos^{-1}(0.8)$,ϕ=36.86

Sin (36.86) =0.6

2. Adjust 5KΩ VAR/p.f. pot till the output at terminal block 18 and terminal block 19 is minimum (ideally signal level is zero) for the following current.

1. for 0.8 power factor

ACA-3	ACA-1(Icosϕ)	ACA-2(Isinϕ)
1	0.8	0.6
0.8	0.64	0.48
0.6	0.48	0.36
0.4	0.32	0.24

Table.4.2

2. for 0.85 power factor:

ACA-3	ACA-1(Icosϕ)	ACA-2(Isinϕ)
1	0.85	0.52
0.8	0.68	0.42
0.6	0.51	0.31
0.4	0.34	0.21

Table.4.3

3. Varying 5KΩ VAR/p.f. pot position for the above set current and check for voltage shift from negative to positive at TB18 &TB19.(change in pf setting).

4. Vary (reduce) Icosϕ (ACA-1 and keeping ACA-2 constant) for the above current and check for voltage change at TB18 and TB19. (Observe voltage variation from positive to negative zone).

5. Bring back ACA-1(Icosϕ) to initial position and vary [reduce] Isinϕ for the above current and check for voltage changes at TB18 and TB19.

Advantages & Applications of VAR/p.f regulator

Advantages

- Un manned control
- Semiautomatic
- Limits the rotor current
- Easy regulation

Applications

- The major application of Var/pf regulator is used on all hydro and turbo driven
- Generators and commercial diesel generator sets.

CONCLUSIONS

To support the grid in meeting the power demand. Electricity board will buy power from different agencies. So, that the deficiency in power is compensated. Hence, power generation like co-generation, diesel power generation, and steam power generation are encouraged. During the process of power feeding to grid any change in grid will lead to change in var delivered by the generator feeding to grid. Hence, generator is operating either in varying power factor or varying Var according to mode set. Power factor/VAR regulator is excited to ensure that the generator working either in constant VAR or in constant power factor control.

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