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A Smart Way of Switching Loads in Automatic Voltage Regulator Loop by Predicting its Gain Margin

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Abstract— Constancy of the Generator terminal voltage is achieved by Automatic Voltage Regulator (AVR) loop. Conventional AVR uses supply dispatch where it senses the voltage changes only after the load gets connected to the grid. This paper attempts to implement demand dispatch such that the loads are made smart and can predict the voltage change in the system before they get connected to the grid. The excitation of the generator is changed prior to the load getting connected, thus preventing voltage collapse due to reactive power changes.The simulation results are obtained using MATLAB for a three phase induction motor by predicting its change in voltage before it connects to the AVR loop.

Index Terms— Automatic Voltage Regulator (AVR), Demand Dispatch, Reactive Power,Smart Load, Supply Dispatch,Three phase induction motor, Voltage Collapse.

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1 Introduction

POWER Quality in a power system is determined by various parameters, two of which are voltage and frequency.To maintain these parameters within standard limits, two control loops are used in the generation side – Automatic Voltage Regulator (AVR) loop and Automatic Load Frequency Control (ALFC) loop. Even though the conventional AVR loop is used to maintain voltage within specified limits, there still exist certain issues such as reactive power changes leading to voltage collapse, which are required to be addressed. On 30th July 2012, India experienced one of the worst blackouts in its history. Although real power flow in the 400kV Bina-Gwalior-Agra link was relatively low, the reactive power flow in the line was higher, resulting in lower voltage at one end due to overdrawal by utilities [1].

The proposed method is to make the loads smart such that they predict the voltage change they would cause and then decide whether they should connect to the grid or not. Thus, load adjustment feature of smart grids is incorporated into the existing AVR loop, converting the supply dispatch based AVR into demand dispatch based AVR [2].

2 Existing Excitation System

2.1 Block Diagram

The Automatic Voltage Regulator loop is used to control the magnitude of the terminal voltage V. The terminal voltage depends on the reactive power output of the generator. The sensitivity and variations of bus voltages with respect to reactive power injections or absorptions are determined by the Q-V characteristics of the generator [3]. The terminal voltage is continuously sensed, rectified, smoothened and the dc signal is compared with a dc reference V_{ref} [4]. The resulting error voltage, after amplification and signal shaping, is fed as input to the exciter which delivers the voltage v_f to the generator field winding [5].

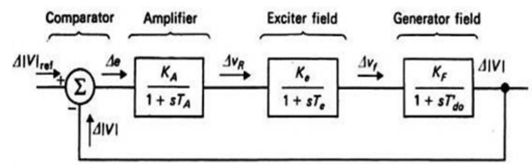

Fig.1 Block diagram of AVR Loop.

Artificial intelligence techniques like Continually Online Trained(COT) Artificial Neural Networks (ANN) has been designed for turbogenerators which can replace conventional Automatic Voltage Regulator (AVR) to meet the increasing complexity of power system [6].

2.2 Closed Loop Analysis of AVR

From the block diagram, the gain and time constants of AVR are as follows:

K_A – Gain of amplifier
K_e – Gain of Exciter
K_F – Gain of Field
T_A – Time constant of amplifier
T_e – Time constant of Exciter
T'_{do} – Transient Time constant of Generator Rotor

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The overall closed loop transfer function of AVR is

$$\frac{\Delta v(s)}{\Delta v_{ref}(s)} = \frac{G(s)}{1+G(s)} \tag{1}$$

Where $G(s) = \dfrac{K_A K_e K_F}{(1+sT_A)(1+sT_e)(1+sT_{do}^{'})}$ (2)

Gain margin of G(s) gives the factor by which gain can be changed such that the closed loop system goes to the verge of instability [7].

The steady state output voltage ΔV_{static} of AVR is given by [8]

$$\Delta v_{static} = \frac{K}{1+K}\Delta v_{ref} \tag{3}$$

Where $K = K_A K_e K_F$ (4)

2.3 Effect of Generator Loading

When a load connects to the generator terminals, the gain of the load affects the gain of the generator, causing a change in the output voltage of the generator i.e. a change in K_F causes a change in overall open loop gain K, affecting ΔV_{static}.

3 Introduction Of Load Adjustment Feature In AVR

From (3), it is evident that if the change in K due to the connection or disconnection of loads can be found beforehand, the corresponding change in voltage that it might cause can also be found prior to its connection to the system.

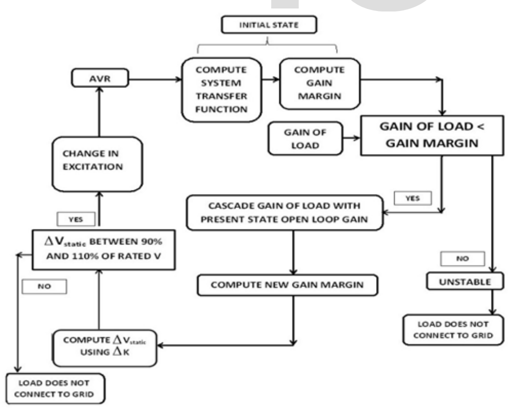

Fig.2. Flowchart of Load Adjustment Feature In AVR.

The gain margin of open loop transfer function G(s) of AVR at the initial state is first computed. Whenever a load wants to get connected to the generator terminals, it must check its steady state gain against the computed gain margin. Gain margin should be greater than or equal to 6dB for obtaining a stable, non-oscillatory voltage regulator system [9]. Here, the steady state gain of load must be obtained from the electrical equivalent transfer function of the load.

If gain of the load is less than the gain margin, it is cascaded with the present state open loop gain and new gain margin of the system is computed. Using (3), steady state voltage change is computed. If this change maintains the system voltage within tolerable limits i.e. 90% to 110% of rated terminal voltage, then generator excitation is suitably changed to provide for the change in voltage that the load might cause if it gets connected. Finally, the load gets connected to the system without affecting its stability. Thus the loads are made smart and load adjustment feature of smart grids is introduced in conventional AVR.

However, in case gain of the load exceeds the gain margin or if change in voltage produced by the load is beyond acceptable limits, the load does not get connected to the system, in keeping with the principle of demand dispatch of smart grids.

In case subsequent loads are to be connected one after the other, the gain margin is updated at each step and the gain of the incoming load is compared against the updated gain margin of the system. The change in voltage is predicted using the updated change in open loop gain ΔK.

4 Simulation Results

The simulation results have been obtained for a three phase, 400V, 1450 rpm, 50Hz wound rotor Induction Motor connected to the generator terminals.

The values of gain constants and time constants mentioned in (2) are given below [10].

K_A= 10, T_A= 0.1
K_e= 1, T_e= 0.4
K_F= 0.8, T'_{do}= 1

The dc reference voltage is obtained using the equation for a three phase rectifier given by

$$v_{ref} = \frac{3v_m}{\pi} \tag{5}$$

where V_m is the maximum voltage of the generator. The value of V_{ref} used for simulation is 540.189V.

4.1 Closed Loop Response for Step Input without Load

Even during no-load condition, the set reference value will not be mirrored at the generator terminals because of the open loop gain K from (4). Thus, from the set values for (2), the steady state voltage on no-load calculated from (3) is

$$\Delta v_{static} = \left[(10\times1\times0.8) \big/ \left(1+(10\times1\times0.8)\right) \right] \times 540.189$$

$$\Delta v_{static} = 480.168 \tag{6}$$

The steady state error of the above system is given by

$$\Delta e(s) = \Delta v_{ref}(s) - \Delta v_{static}(s) \tag{7}$$

Thus, $\Delta e(s) = 540.189 - 480.168 = 60.021V$

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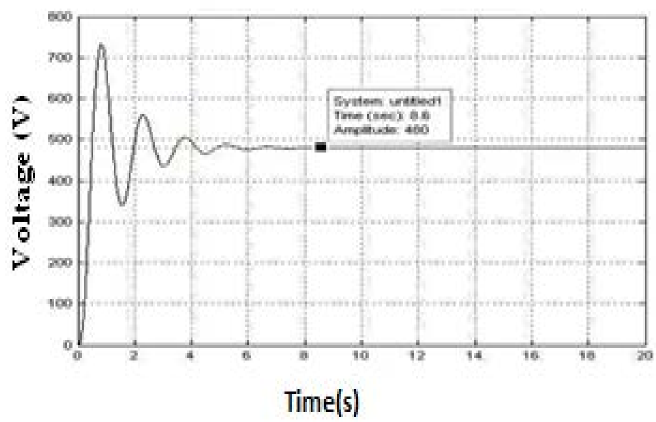

Fig. 3. Closed loop response for step input without load

4.2 Closed Loop Response for Step Input On Load Without Compensation:

When the three phase induction motor is connected to generator terminal, the voltage drops from the value obtained in (6) and not from Vref.

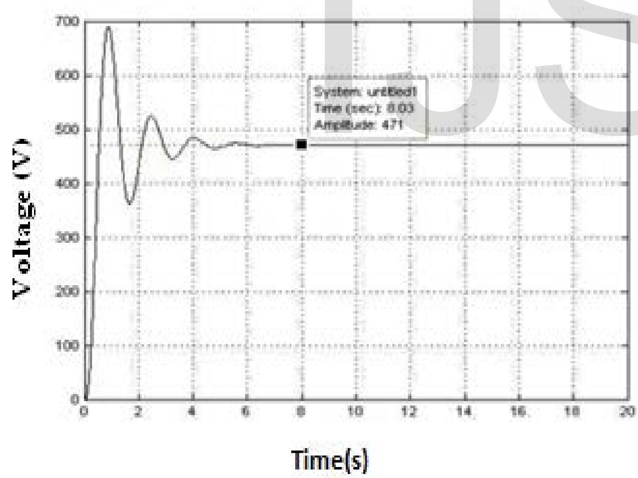

Fig 4 Closed loop response for step input on load without compensation

The change in voltage produced by the three phase induction motor when connected to the generator terminals is

$$\Delta v = 480.168 - 471 = 9.168V$$

Thus, ΔV is predicted before the motor gets connected to the generator terminals. Accordingly, generator excitation is varied to nullify the reactive power change and prevent voltage sag when the motor gets connected. But, the settling time and peak overshoot are high when stability compensation is not used

4.3 Closed loop response for step input on-load, with Compensation

In order to decrease the settling time and to reduce the transient oscillations when the load gets connected, a series compensator is always used in AVR with its time constant T_C equated to T_e [11].

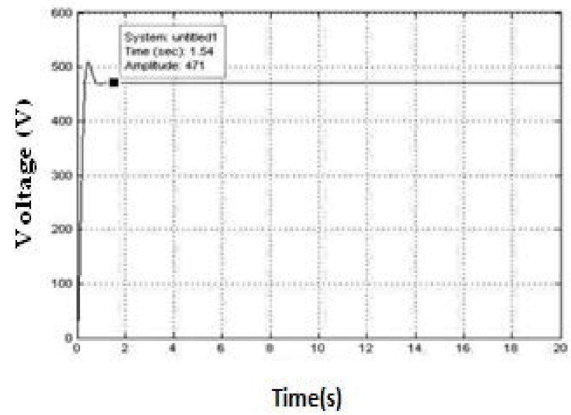

Fig. 5 Closed loop response for step input on load with compensation.

As can be seen from the simulation result for closed loop response for step input on-load, with compensation, the same voltage drop is produced as the uncompensated case, but the oscillations and settling time are reduced significantly.

4.4 Closed loop response for step input on-load, with Compensation, after excitation is increased

Since the change in voltage has been found before the load gets connected, the excitation can be increased so that ΔV can be nullified. This is achieved when the motor communicates the change in voltage it might cause, to the generator, before getting connected. Change in excitation should fall within the limits of Over Excitation Limiter (OEL) and Under Excitation Limiter (UEL) of the generator [12].

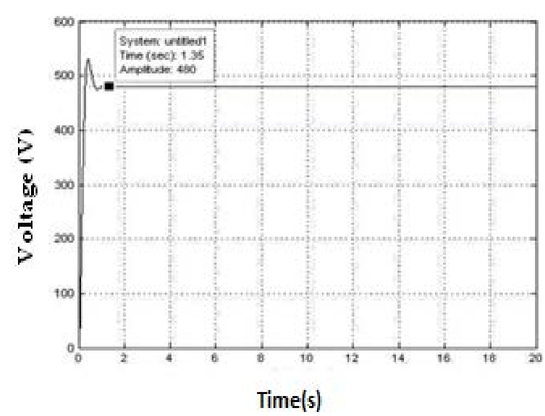

Fig 6 Closed loop response for step input on-load,with compensation after excitation is increased.

From the simulation result, it can be observed that the steady state voltage on-load is the same as steady state voltage without load such that ΔV is nullified.

5 Conclusion

In conventional AVR, communication is one-way i.e. only from generator to load. By introducing the load adjustment feature in AVR, communication is made two-way i.e. the load can also communicate with the generator, which can be observed from the simulation results [13].

Demand dispatch helps in optimizing reliability, peak load management and energy efficiency resulting in the most economical price for electricity. A potential application of the demand dispatch method is grid integration of renewable energy [14]. Due to the discontinuous nature of natural forces such as solar energy and wind speed, the MW and MVA generated in a hybrid grid might vary with time. In such situations, two-way communication between the load and the grid will prevent instability due to non-availability of supply and over-drawing from the lines. Thus, reactive power flow control using AVR can be implemented such that a 'prevention is better than cure' approach is adopted.

Future challenges to the proposed method include increased time complexity, cost effectiveness, its application to variable load devices considering the feedback with rectifiers and filters instead of unity feedback [15].

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