2017 2nd International Electrical Engineering Conference (IEEC 2017)
May 19th -20th, 2017 at IEP Centre, Karachi, Pakistan

Comparative analysis of ST1A and ST2A excitation system models for voltage stability of alternator

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Abstract: Excitation system governs the response of alternator regarding reactive power (Q) supply from it. Different excitation models have been developed in past years to predict the generator response for stability of power system operation. Static excitation systems are most widely used Q-control system due to merits over other systems. In this paper, we have done a comparative study to investigate the response of ST1A and ST2A excitation system models under different operating conditions. ST1A models the potential-source controlled-rectifier excitation system while ST2A compound-source rectifier excitation systems. Two areas four machine power system configuration is used for analysis. Simulation work is carried out on Simulink (MATLAB) and the responses of two exciters under different circumstances have been discussed. The key focus in this comparative study is on the response of exciter voltage and corresponding generator terminal voltage. The principle result of this simulation is that under bolted fault conditions in power system, ST2A performance is considerably better from the perspective of terminal voltage stability and rotor oscillations as compare to ST1A.

Keywords: Reactive power control, ST1A & ST2A excitation systems, Voltage stability.

I. INTRODUCTION

Power system stability is considered as one of the important aspect for safe and reliable operation of the system. The increasing demand of reliability and stability in the power system emphasizes the need of system studies. The operational parameters that may lead to instability situation in the power system are the voltage, frequency and rotor angle. Power system stability studies can be classified as steady-state and transient stability. Classification of stability depends on magnitude of disturbance(steady/transient state), on time duration(short/long term) and nature of the parameter(Voltage/frequency/rotor angle) gets affected subjected to any disturbance in operation[1]. The importance of stable operation has been depicted by major blackouts in the history of power system around the world. Power system smooth operation depends mainly on the operating characteristics of generator's active and reactive power control while operating within the thermal limits[2, 3].

In steady-state stability, generator dynamics may change due to small perturbations in load change while in transient stability the impact on generator dynamics will be severe. Three phase fault creates most severe impact on the system as the generator accelerates at higher rate due to large imbalance in applied mechanical and counter electrical torque on it[2]. Both governor and exciter play important role for the stability of the system. Response from the governor is sluggish in nature due to mechanical operation while exciter response is much faster due to electromagnetic nature of transient[3]. The governor response in case of mentioned disturbances has not been discussed as it is beyond the scope of this paper.

Excitation system of alternators can be classified as DC, AC and Static system. Static excitation systems can be further categorized as compound source rectifier system, potential source and compound controlled rectifier excitation system[4]. Alternators from the perspective of reactive power control can be operated in voltage, droop, power factor or reactive power control mode [5, 6]. In this paper, voltage control mode of the generator is set using built-in models of ST1A and ST2A in MATLAB with typical values.

This paper comprises of two major sections of literature study and analytical results. The first section briefly discusses the exciter models used in this simulation while the later section presents the comparative results of both excitation models. Responses of the excitation systems under the operating conditions having normal load on generator, small perturbation in load and the occurrence of three phase fault have been discussed. ST1A and ST2A excitation models for alternators are among the standard models used in MATLAB. The basic idea and key limitations of these models have been summarized in this paper. In reference[7], detailed description of these models have been discussed.

II. SECTION ONE: LITERATURE REVIEW

A. ST1A Excitation System

ST1A represents potential-source controlled rectifier system of excitation. In this model, excitation power is supplied through transformer from generator terminals which is then regulated by controlled rectifier.[1] The excitation voltage may either of positive or negative polarity depending upon the firing angle of switching device (Thyristor).[7] The inherent delays in the system due to components for the required response are very less. Therefore, ST1A a rapid response control in the case of minor disturbances [8, 9].

ST1A takes generator terminal voltage as input signal to respond. Therefore, in the case of three phase bolted fault there is significant voltage drop at the generator terminals and the response of the exciter is not satisfactory. The firing angle of the thyristor affects the output and so the relation for input-output is assumed to be linear and is modeled by voltage regulator gain (K_A). However, the bridge relationship is not linear.

B. ST2A Excitation System

ST2A represents the compound-source rectifier excitation system. This excitation system uses both voltage and current of the generator. Under open circuit, the generator terminal voltage is utilized for the excitation power. In the case of short circuit (three phase fault), the scenario where ST1A is incapable of supplying any excitation voltage, ST2A has the capability of field forcing capability by utilizing current as the input[8]. For the case of inductive load in the local network the UEL is ineffective and so it can be neglected in the modeling[10]. The most sensitive parameter of ST2A is the potential circuit gain (Kp) and it depends upon the excitation circuit design [11].

III. SIMULATED RESULTS

The modeled network of two area four machine system is given in Fig.1. The technical details of the system including generators transformers and loads are given in reference[1].

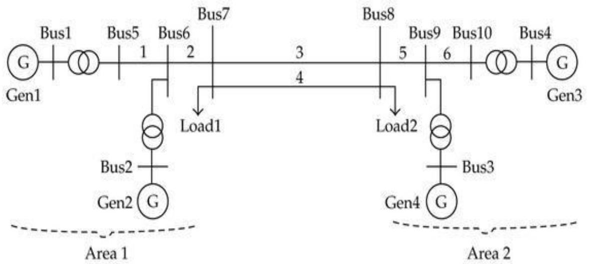

Figure 1: Two area four machine system [1]

The identical steam governor model is used with both excitation systems. For the different scenarios mentioned above, generator terminal voltage and exciter field voltage have been plotted for Gen1 in Fig.2 (a), (b)and (c) using both ST1A and ST2A excitation systems.

A. Under Normal Condition

This case shows the response of two excitation system when the transmission line section between bus 7 and 8 is switched off. The figure 2 below shows the response of the system.

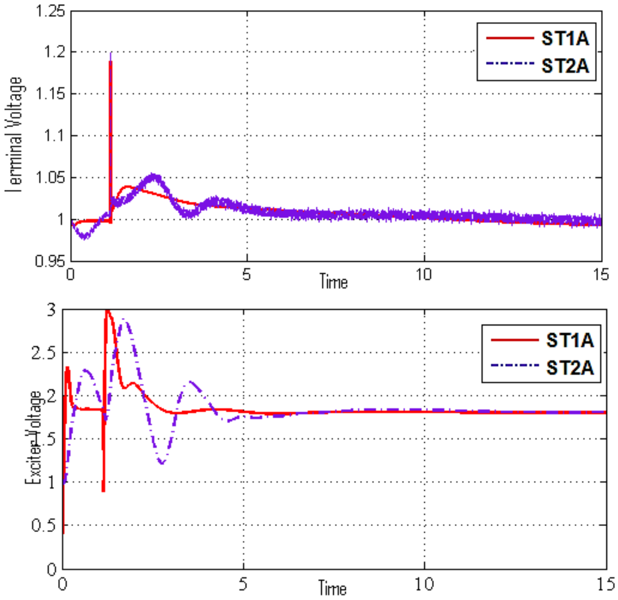

Figure 2: Behavior of two models under normal conditions

Figure 2 shows the sudden rise in the terminal voltage at t=1sec. We have two transmission lines from bus 7 and 8. While simulating the normal condition, one of the transmission line between area 1 and area 2 was connected at the start of the simulation, however the second transmission line between bus 7 and 8 was energized at t=1 sec. Since the length of the transmission line was 220km and we know that capacitive effect is dominant for length greater than 80km[12] so the transmission line acted as the capacitor connected at t=1sec and therefore we can see a rise in the terminal voltage[13].

B. Small Disturbance

Now assume that the load of 0.967p.u. has been rejected from the system in area 1 at 8 sec. The response of both the systems is shown in the Fig. 3.

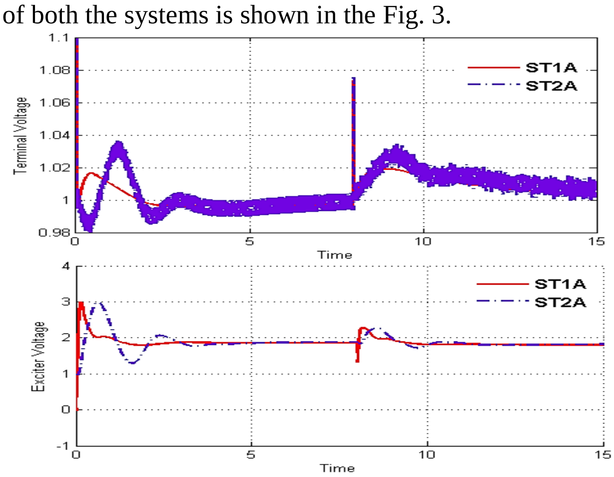

Figure 3: Behavior of two models under load rejection

Figure 3 shows the role of the exciter for maintaining the terminal voltage. It can be observed that the action of exciter is in contrary to the terminal voltage that is if the terminal voltage is rising than the exciter reduces its voltage to reduce the terminal voltage and vice versa. The load considered for simulating small disturbance is 9% more than the load considered for simulating the constant load condition (Normal condition as discussed above). Since the load is rejected in area 1 at 8 sec, we can see there is a rise in the terminal voltage and so the exciter reduces its voltage to maintain the terminal voltage to 1 p.u. Due to inherent delays of the two exciters, it can be observed that the terminal voltage took some time to maintain its voltage to 1 p.u.

C. Fault Condition

Now assume that there is a three-phase fault in between bus 7 and bus 8 at the transmission line. Two conditions, rapid clearance and prolong fault duration are simulated:

1. When the fault occurs at 6 sec and cleared at 6.085 sec.(Rapid clearance of fault)
2. When the fault occurs at 6 sec and cleared at 6.2 sec.(Prolong condition of fault)

The responses of system in both conditions are shown in the figure 4(a) and 4(b) respectively.

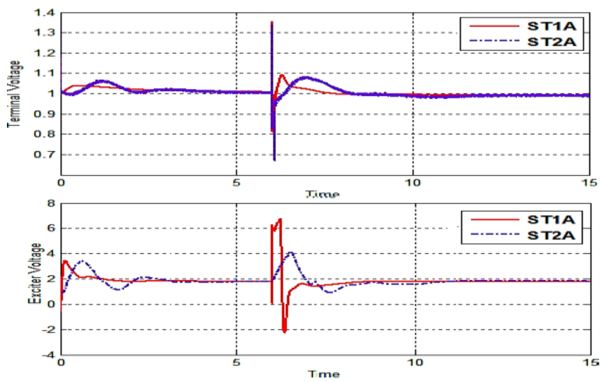

Figure 4(a): Rapid clearance of three phase fault

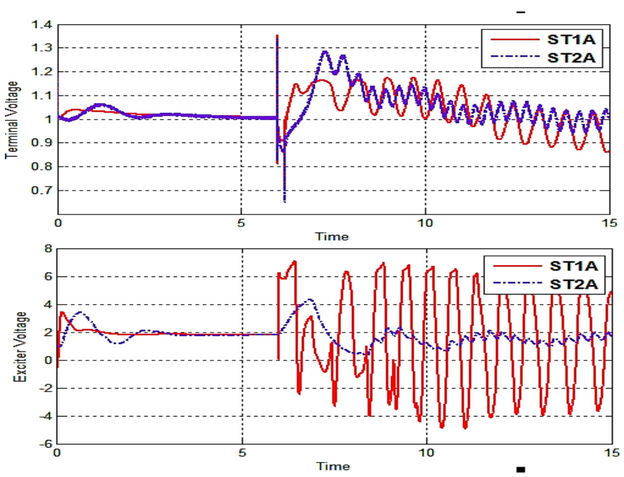

Figure 4(b): Prolong clearance of three phase fault

Figure 4(a) and 4(b) depicts two cases for faults. Since the time for which the fault considered in figure 4(a) is 0.085sec, so as soon as the fault is cleared both the exciters are able to maintain the desired terminal voltage with ST1A taking less time to maintain the desired voltage as compare to ST2A. Though, ST1A is non-responsive in the case of fault, but the fast response of exciter enables to maintain the voltage stability. The effect of fault location and fault and clearing time[14] are the influential factors that are considered while doing transient stability analysis. The stability of power system depends upon the fault clearing time. In figure 4(a) the system sustains its stability and the voltage settles to 1pu. However, the case depicted in figure 4(b), the rotor angle of the machine diverges and so we observed pole slipping condition, thus the voltages are oscillating at higher rate.

IV. CONCLUSION

In this paper, the response of the two-excitation systems has been compared successfully. Under normal conditions the response of ST1A is better than ST2A. The generator terminal voltage settles quickly for ST1A excitation system. However, in case of three phase fault ST1A excitation system failed to apply field forcing whereas ST2A provides it. Furthermore, it is observed that ST2A response is less oscillatory than that of ST1A for prolong fault duration but under normal circumstances ST2A shows oscillations in the terminal voltage of alternator.

V. FUTURE WORK

The comparative study of two exciters has opened a window for this work to be extended. The paper presented the response of the two exciters under different situation that occurs or may occur at the generation side. However, if we notice from figure 2 to figure 4, ST2A showed more oscillations than the ST1A so this can be investigated and extended in future work. Moreover, both the exciters take PSS inputs so the work can be extended as what is the best combination of exciter model and the PSS model. While doing model validation, step responses of the two exciters are essential so this work can be further extended by observing its step response.

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