Dynamic Stability Modified IEEE 3 Generator 9 Bus With 50 MW Power Injection of Generator XY

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***Abstract* – The existence of new power injection at a system will effect system stability that existed before, so stability analyze was needed to know the system conditioning before and after power injection, and performance system after disturbance, by observe rotor angle, frequency, and voltage. The result of dynamic system show that power injection of Gen XY can supply 0,021 pu at bus 1, 0,001 at bus 2, 0,001 at bus 3, 0,0261 pu at bus 4, 0,0366 pu at bus 5, 0,0186 pu at bus 6, 0,0101 pu at bus 7, 0,0083 pu at bus 8, 0,0061 pu at bus 9. When 3 phase fault during 1-2 second happened, the frequency and rotor angle increasing. When generator XY inject system with 50 MW, the modified IEEE 3 Generator 9 Bus become increase with frequency 60.27 Hz, voltage profile increasing, rotor angle decreased close to normal conditions.**

Keywords–Dynamic system stability; power injection; frequency stability; voltage stability; rotor angle stability.

I. Introduction

The power system not growing fast, it make so many researches appear. Voltage stability analyze, repair by using FACT device and various modification has been done to fix performance system [1]. Trending topics at this time is about power injection to fulfill electrical demand. Various studies that learn about power injection have been done [2]. But, those studies perform injection at line that was already existed before.

This research focuses on power injection at power plant by adding generator to the system that was already existed. Voltage, frequency, and rotor angle transformation will be discussed in this paper. By use of system IEEE 3 generator 9 bus, dynamic stability study will discussed and simulated to test the performance of the system that was already existed.

Power-injection by fixing performance of system dynamic stability and its connection with FACT devices was already discussed at [3]. Assessment of various researches that was emphasized at additional devices was already discussed at [4]-[7].

II. Methodology

A. Power Flow [8]

Power flow studies is one of study that very important to plan and build an electrical system for the future as well as to determine the best operation from systems that was already existed. Power flow studies can give information about voltage, current, active power, reactive power, and power factor that exist in the system. That information can be used to evaluate power system performance and to analyze the condition of generation or loading. In the power flow studies, busses are divided into 3 kind of bus, which is:

- Load bus
- Voltage controlled bus or generator bus
- Slack bus (swing bus) or reference bus

In every bus there are 4 kind of quantity, which is:

- Real power or active power (P)
- Reactive power (Q)
- Voltage scalar (|V|)
- Voltage phase angle (θ)

In every bus there are two kind of quantity that was determined before, while 2 others quantity are final result from power flow calculation. Determined quantity can be seen at Table I as follows:

TABLE I. Bus Quantity Determination

Type of Buses	Specify	Unknown
Slack (swing)	$\|V\|$, θ	P , Q
Voltage Controlled (PV Bus)	P , $\|V\|$	Q , θ
Load (PQ Bus)	P , Q	$\|V\|$, θ

The equation of work method of electrical power system can be stated in admittance form as follows:

$$I_{bus} = Y_{bus} V_{bus} \quad (1)$$

Where :
I_{bus} : Bus current that was injected (A)
Y_{bus} : Bus admittance matrix (℧)
V_{bus} : Bus voltage (V)

Current injection at bus I can be formulated with equation as follows:

$$I_i = \sum_{n=1}^{N} Y_{in} V_n \quad (2)$$

where :
I_i = current at bus i
V_n = voltage at bus n
Y_{in} = impedance between bus i and bus n

Equation (2) in polar form is:

$$I_i = \sum_{n=1}^{N} |Y_{in}||V_n| \angle \theta_{in} + \delta_n \quad (3)$$

Active power and reactive power at bus i are:

$$P_i + jQ_i = V_i I_i \text{ ......(4)}$$

Or

$$I_i = \frac{P_i - jQ_i}{V_i} \text{ ......(5)}$$

Where:

I_i = current at bus i

V_i = voltage at bus i

P_i = active power at bus i

Q_i = reactive power at bus i

Iteration mode was used to solve power flow equation, estimated value was used to find out unknown bus voltage, and new value at every bus voltage can be calculated from other bus estimated values. In this paper, method that was used is Newton-Raphson. This method applies modification of taylor series to get derivative of mathematic equation as iteration calculation basic that involve matrix jacobian. By substitute equation (3) to equation (4) we have:

$$P_i + jQ_i = |V_i| \angle\delta_i \sum_{n=1}^{N} |Y_{in}||V_n| \angle\theta_{in} + \delta_n \text{ ......(6)}$$

Or

$$P_i + jQ_i = \sum_{n=1}^{N} |V_i||V_n||Y_{in}| \angle(\theta_{in} + \delta_n - \delta_i) \text{ ......(7)}$$

By separating real part and imaginer part, we have real power equation at bus i, which is:

$$P_i = \sum_{n=1}^{N} |V_i||V_n||Y_{in}| \cos(\theta_{in} + \delta_n - \delta_i) \text{ ......(8)}$$

Reactive power equation at bus i are:

$$P_i = -\sum_{n=1}^{N} |V_i||V_n||Y_{in}| \sin(\theta_{in} + \delta_n - \delta_i) \text{ ......(9)}$$

Equation of voltage phase angle and new voltage are:

$$\delta_i^{(k+1)} = \delta_i^{(k)} + \Delta\delta_i^{(k)} \text{ ......(10)}$$

$$|V_i^{(k+1)}| = |V_i^{(k)}| + \Delta|V_i^{(k)}| \text{ ......(11)}$$

Where:

$\delta_i^{(k+1)}$: new voltage phase angle

$\delta_i^{(k)}$: old voltage phase angle

$\Delta\delta_i^{(k)}$: correction value of voltage phase angle

$|V_i^{(k+1)}|$: new voltage

$|V_i^{(k)}|$: old voltage

$\Delta|V_i^{(k)}|$: voltage correction value

B. Power System Stability

Power system stability is system ability to back to normal condition after goin to a disturbance. System instability will cause system lost its synchronous. Therefore, stability issues are connected with synchronous machine assessment after disturbance. Generally, stability issues are divided into two main categories, which is steady state stability and transient stability. Steady state stability expansion was known as dynamic stability [8].

C. Dynamic System Stability

Dynamic system is system ability to back to normal condition that was focused after going to a disturbance by entering automatic control component to see system performance. Those that are analyzed at dynamic system stability are voltage stability, frequency stability and rotor angle stability [8].

1) Voltage Stability

Voltage stability refers to system ability to maintain voltage so that its voltage still stable at its nominal range at every bus before and after going to disturbance. Instability can cause voltage decrease or increase at bus. Voltage instability can cause the loss of system integrity like loss of load or break of transmission line at voltage area that reach low value. Main factor that cause those conditions are when active and reactive power flow through inductive reactance at transmission line [9].

2) Frequency Stability

Frequency stability refer to system ability to maintain frequency value so that its value still stable at its nominal range after going to large disturbance at the system that cause significant unbalance between generator and load. Those depend on system ability to restore balance between generator and load. Large system disturbance usually causes changing of frequency, voltage, power flow, and other system variables. Generally, frequency stability issues are related with device responsive inability, bad coordination in control [9].

3) Rotor Angle Stability

Rotor angle stability in a synchronous machine refers to synchronous machine ability that was interconnected to stay sync after going disturbance. Rotor angle instability cause enhancement of swing angle of several generators, so those generators lost their sync with other generator [9]. Main activator gives a mechanic torque (T_m) at machine axis and machine produces an electromagnetic torque (T_e). During disturbance, mechanic torque is bigger than electromagnetic torque and produce acceleration torque (T_a). The equation are:

$$J \frac{d^2\theta_m}{dt^2} = T_a = T_m - T_e \text{ ......(12)}$$

Where:

T_a = Accelaration Torque

T_m = Mechanic Torque

T_e = Electromagnetic Torque

The changing of electromagnetic torque (T_e) of synchronous machine because of disturbance can be solved with two ways, which are:

- Synchronization of torque component, in phase with deviation rotor angle.

- Damping of torque component, in phase with deviation velocity.

System stability depends on those two torque component for each synchronous machine [9].

III. Implementation

This research was performed at IEEE System 9 bus with data modification using *ETAP Power Station* with license name of ITN malang is INSTEKNAMA. Simulations that will be performed are load flow and transient stability analysis. To understand the condition before new power injection, load flow can be used. If there are bus conditions below allowed margin (Vpu = 0,95-1,05) then reparation with new generation injection can be performed. Meanwhile, transient stability analysis can be used to know voltage stability, frequency stability, and rotor angle stability so that system performance before and after new power injection can be known.

Injection is not done on G2 and G3 because both generators are considered fixed and nothing new generator added. New generator which is Gen XY will be added to this system and will be injected to bus 5 to fulfil power deficiency at the system after the 3 phase fault. Single line of System IEEE 3 generator 9 Bus after addition of Gen XY can be seen at Fig. 1.

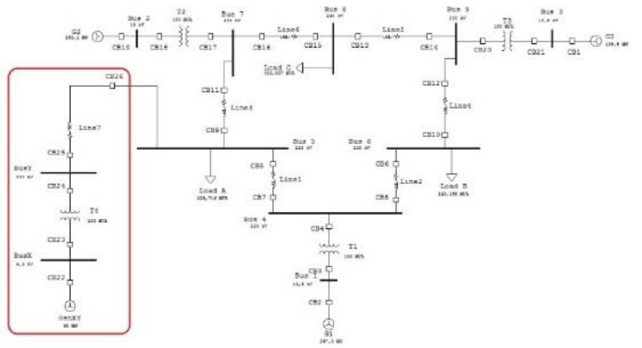

Fig. 1. Single Line of System with the addition of Gen XY

In this first system, there are 3 generator which are G1, G2, G3 and new power that will be injected by Gen XY, where at G2, G3, and Gen XY, exciter control and governor with data sample at application has been added. Beside that, dumping value as much as 5 was also added to those generators, as we can see at Table II as follows:

TABLE II. Generator Data

Rating Generator	ID Generator			
	G1	*G2*	*G3*	*Gen XY*
Operating	Swing	Voltage Control	Voltage Control	PF Control
MW	247,5	163,2	108,8	50
Exciter	fixed	ST1A	ST1A	ST1
Governor	fixed	ST	ST	ST
Damping	5	5	5	5

Those three generators will be supply 3 loads which is Load A, Load B, dan Load C with each quantities that can be seen at Table III as follows:

. TABLE III. Load Data

ID Load	Rating Load	
	MW	*Mvar*
Load A	325,825	50,502
Load B	189,14	21,502
Load C	96,879	33,894

IV. Simulation Result

At this stability test of system IEEE 9 Bus there are 3 conditions that will be seen which is normal condition, 3 phase fault condition, and after injection condition with regard to changing of voltage, frequency, and rotor angle.

A. Normal Condition (Before Injection)

The simulation result before 3 phase fault and new power injection shown at Fig. 2.

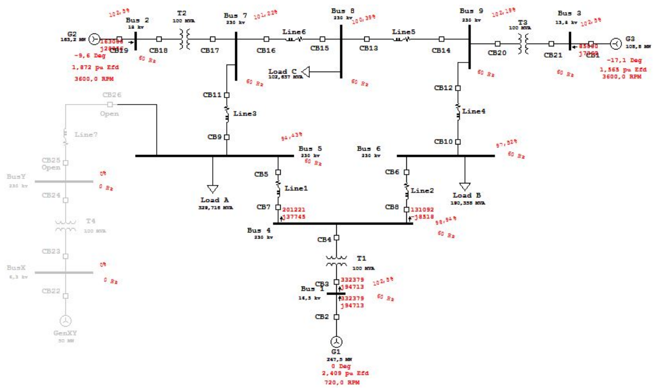

Fig. 2. Normal Condition

Base on condition at Fig. 2, parameter value quantity like voltage, frequency, rotor angle in the normal system condition can be summarized at Table IV and Table V as follows:

TABLE IV. Voltage Stability and Frequency Stability In Normal Condition

ID Bus	Normal Condition (Before)	
	V (pu)	*f (Hz)*
Bus 1	1,025	60
Bus 2	1,025	
Bus 3	1,025	
Bus 4	0,9894	
Bus 5	0,9443	
Bus 6	0,9752	
Bus 7	1,0122	
Bus 8	1,0039	
Bus 9	1,0219	

TABLE V. ROTOR ANGLE STABILITY IN NORMAL CONDITION

ID Generator	Normal Condition (Before)
	Rotor Angle (Degree)
G1	0
G2	-9,6
G3	-17,1

In this normal condition, bus voltage values other than bus 5 were still located in allowed value range, voltage values at bus 5 is below allowed value which is 0,9443 pu because of power-supply deficienly, therefore new generator power-supply addition was needed to be done to fulfil those deficiencies.

B. 3 Phase Fault Condition

In system condition during 3 phase fault, the fault placed at bus 6 during 1 second until 2 second. Disturbance simulation result can be seen at Fig. 3, Fig. 4, Fig. 5.

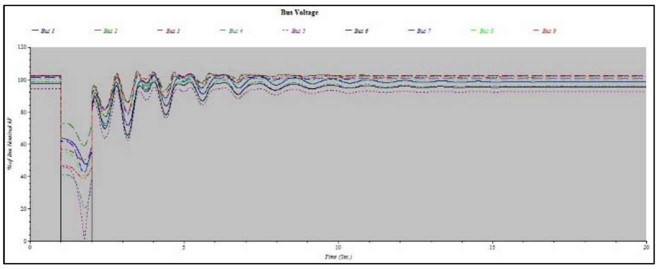

Fig. 3. Voltage Stability During 3 Phase Fault Condition

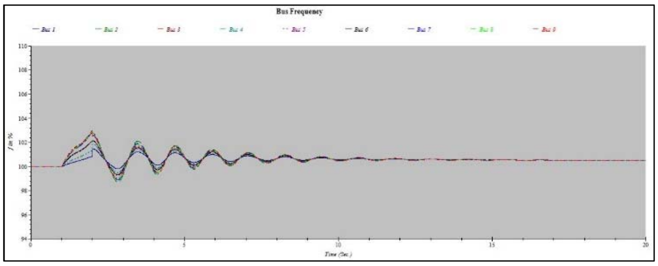

Fig. 4. Frequency Stability During 3 Phase Fault Condition

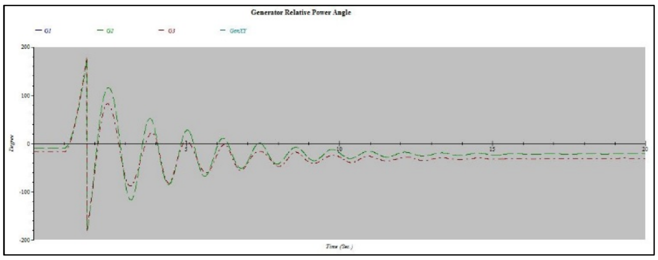

Fig. 5. Rotor Angle Stability During 3 Phase Fault Condition

Base on simulation result at Fig. 3, Fig. 4, and Fig. 5, parameter value quantities like voltage stability, frequency stability, and rotor angle stability during 3 phase fault can be summarized at Table VI and Table VII as follows:

TABLE VI. VOLTAGE STABILITY AND FREQUENCY STABILITY DURING 3 PHASE FAULT CONDITION

ID Bus	3 Phase Fault Condition	
	V (pu)	*f (Hz)*
Bus 1	0,6344	60,06
Bus 2	0,7282	60,25
Bus 3	0,5668	60,29
Bus 4	0,4119	60,11
Bus 5	0,4575	60,18
Bus 6	0	60,19
Bus 7	0,6191	60,25
Bus 8	0,5492	60,26
Bus 9	0,4677	60,28

TABLE VII. ROTOR ANGLE STABILITY DURING 3 PHASE FAULT CONDITION

ID Generator	3 Phase Fault Condition
	Rotor Angle (Degree)
G1	0
G2	-21,1
G3	-30,4

In this system condition during disturbance, voltage stability decrease at every busses and the lowest value is at the bus 6, frequency stability increase from the first condition in range 60,06-60,29 Hz at every bus, rotor angle stability G1 was unaffected which is 0 degree, still at its working point, but for G2 And G3, their rotor angle stability decrease -21,1 degrees and -30,4 degrees sequentially then they work at those new working points.

C. After Injection Condition (Gen XY injected)

System condition after Gen XY Injection on bus 5 at 3 second can be seen at Fig. 6, Fig. 7, Fig. 8.

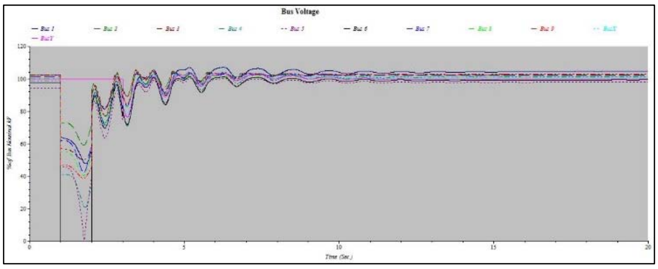

Fig. 6. Voltage Stability after Injection Condition

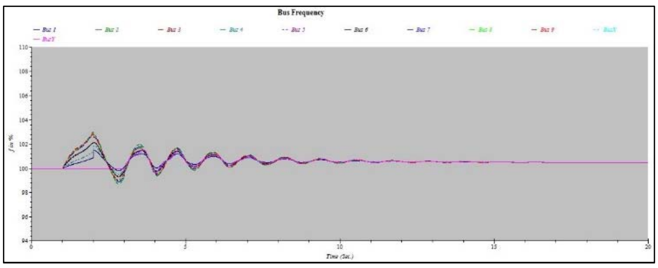

Fig. 7. Frequency Stability after Injection Condition

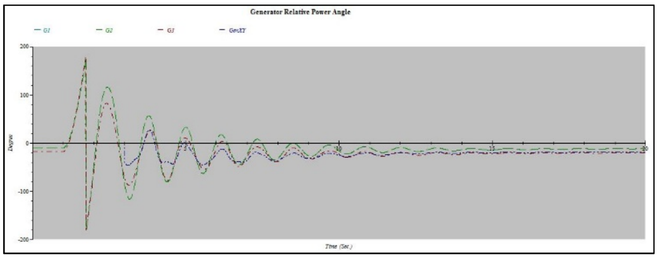

Fig. 8. Rotor Angle Stability after Injection Condition

Base on system simulation result at Fig. 6, Fig. 7, and Fig. 8, parameter value like voltage, frequency, and rotor angle after Gen XY injection can be summarized at Table VIII and Table IX as follows:

TABLE VIII. VOLTAGE STABILITY AND FREQUENCY STABILITY AFTER GEN XY INJECTION

ID Bus	After Gen XY Injection Condition	
	V (pu)	*f (Hz)*
Bus 1	1,0469	60,27
Bus 2	1,026	
Bus 3	1,026	
Bus 4	1,0155	
Bus 5	0,9809	
Bus 6	0,9938	
Bus 7	1,0223	
Bus 8	1,0122	
Bus 9	1,028	
Bus X	1,003	
Bus Y	0,9999	

TABLE IX. ROTOR ANGLE STABILITY AFTER GEN XY INJECTION

ID Generator	After Gen XY Injection Condition
	Rotor Angle (Degree)
G1	0
G2	-11,1
G3	-19,5
Gen XY	-18,5

In this condition, voltage stability increase at every busses and locate at new working point. Frequency stability increase and work on a new working point which is 60,27 Hz. Meanwhile, rotor angle stability increase at every generator and locate at new working point except at G1 that still locate at first working point.

D. Comparison Test for Every Condition

Base on every condition that has been tested, comparison between every condition with parameters like voltage stability, frequency stability and rotor angle stability can be made asfollows:

TABLE X. COMPARISON OF VOLTAGE STABILITY AND FREQUENCY STABILITY AT EVERY CONDITION

ID Bus	Normal Condition (Before)		3 Phase Fault Condition		After Gen XY Injection Condition	
	V (pu)	*f(Hz)*	*V (pu)*	*f(Hz)*	*V (pu)*	*f(Hz)*
Bus 1	1,025	60	0,6344	60,06	1,0469	60,27
Bus 2	1,025	60	0,7282	60,25	1,026	60,27
Bus 3	1,025	60	0,5668	60,29	1,026	60,27
Bus 4	0,9894	60	0,4119	60,11	1,0155	60,27
Bus 5	0,9443	60	0,4575	60,18	0,9809	60,27
Bus 6	0,9752	60	0	60,19	0,9938	60,27
Bus 7	1,0122	60	0,6191	60,25	1,0223	60,27
Bus 8	1,0039	60	0,5492	60,26	1,0122	60,27
Bus 9	1,0219	60	0,4677	60,28	1,028	60,27
Bus X	-	-	-	-	1,003	60,27
Bus Y	-	-	-	-	0,9999	60,27

TABLE XI. COMPARISON OF ROTOR ANGLE STABILITY AT EVERY CONDITION

ID Generator	Rotor Angle (Degree)		
	Normal Condition (Before)	*3 Phase Fault Condition*	*After Gen XY Injection Condition*
G1	0	0	0
G2	-9,6	-21,1	-11,1
G3	-17,1	-30,4	-19,5
Gen XY	-	-	-18,5

Base on data on table above, comparison charts be arranged as follows:

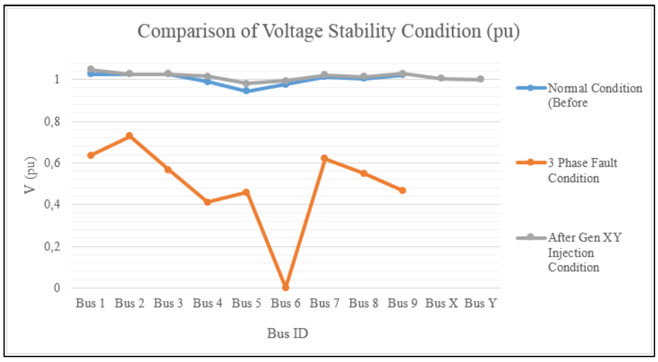

Fig. 9. Comparison of Voltage Stability Condition

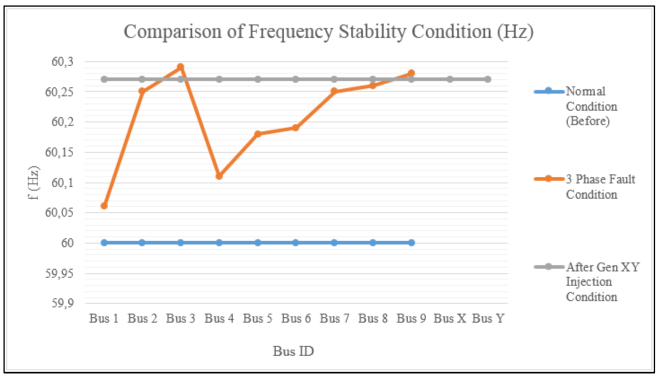

Fig. 10. Comparison of Frequency Stability Condition

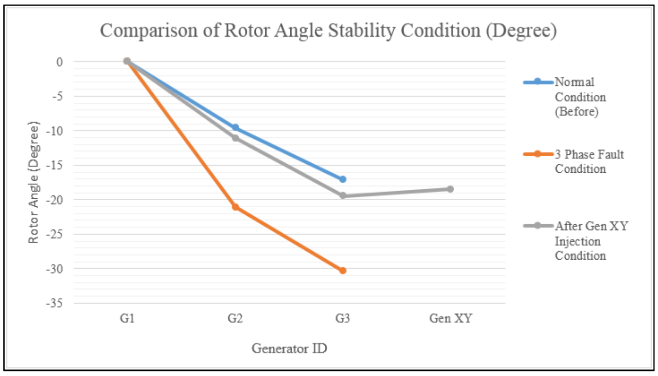

Fig. 11. Comparison of Rotor Angle Stability Condition

Base on simulation result of dynamic system stability before and after Gen XY injection, general description about dynamic system stability can be obtained. Table X, Fig. 8, and Fig. 9 are comparison of voltage and frequency stability. While Table XI and Fig. 10 are comparison of rotor angle stability. After Gen XY injection, system voltage stability increase by an average of 1,01% from the first condition, frequency stability increase 0,27%. While rotor angle stability work on new working point.

V. CONCLUSION

Base on dynamic stability simulation result using modification of system IEEE 3 generator 9 bus as a result Gen XY injection, it can be concluded as follows:

1. The addition of new generator which is Gen XY into the system can fix voltage profile 0,021 pu at bus 1, 0,001 at bus 2, 0,001 at bus 3, 0,0261 pu at bus 4, 0,0366 pu at bus 5, 0,0186 pu at bus 6, 0,0101 pu at bus 7, 0,0083 pu at bus 8, 0,0061 pu at bus, from previous condition.
2. During 3 phase fault for 1 - 2 seconds, voltage stability decrease at every bus. Frequency stability increase and rotor angle stability decrease. But after it was injected by Gen XY at 3 second, voltage and frequency stability increase then stable at a new working point. rotor angle stability increase and stable at new working point near to normal condition.

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