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Impact of DG on Transient Stability in Radial Distribution System

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Abstract - *In the present power grid scenario DG plays a major role. Automation of every system in the world leads to increasing in the penetration level of DG into the power system DG in the system causes the number of advantages like increased in voltage profile, transmission and distribution lines cost reduced and line losses reduced. But with the increasing penetration levels of DG to the network causes the increased in fault current magnitude, bidirectional power flow and transient stability of system is decreased. In this work mainly focused on the rotor angle stability analysis of the three phase balanced radial distribution network under different fault conditions like LG, LL, LLG and LLLG faults, with different power levels of DG. MATLAB/Simulink software is used for the circuit modeling and results simulation purpose.*

Key Words: **DG (distributed generation), LG(Line to ground fault), LL (Line to line fault), LLG (Double line to ground fault)and LLLG (three phase to ground fault), CCT (critical clearing time).**

1. INTRODUCTION

Distribution systems are designed to operate for the single source which is a grid. Grid supplies power to the load with unidirectional power flow manner. Transient stability analysis is done in the radial distribution network by the consideration of only one grid source as synchronous generator type [1] [2]. But coming to the present power grid scenario the power flow is bidirectional by connecting the DG's to the network. DGs are placed at the load side in order to meet the load requirement. There are number of advantages to the distribution network by connecting the DG like increased in power requirement to the load, transmission and distribution lines cost reduced ,line losses reduced[3].

DG with small scale power generation does not effect on the transient stability of the radial distribution network. But with the increasing penetration level of DG in the system leads to decreasing of transient stability in the network [4] [5].DG's are with synchronous machine type decreases the transient stability of the distribution system. Transient stability plays the major role in the synchronization of machines under fault conditions. The fault current magnitude is also increased with increasing penetration level of DG to the system, with this increased fault current operation of the protection equipment disturbed [6], [7].

2. TRANSIENT STABILITY IN POWER SYSTEM

Stability in power system is defined as the ability of power system to return to stable position after subjected to disturbance. Stability in power system classified into three types and they are steady state stability, dynamic stability and transient stability [8]. Steady state stability determines the upper limit of loading of synchronous machines before losing synchronism. Small and continuous oscillations are occurred in the power system due to damping in the system. For stable system these oscillations are exist for small interval of time after that they are die out ,this type of system is called as dynamically stable system in the dynamically unstable system oscillations are not die out and continuously increasing in magnitude with infinite time interval. Transient stability of the system is defined the ability of the power system to return to stable operation followed by major disturbance like faults, sudden switching of heavy loads, large changes in power angle and sudden changes in speed of the rotor of synchronous machine.

Swing equation governs the dynamics of the synchronous machine. Swing equation is a second order differential equation. In transient state the dynamics of the system is determined by using the swing equation. In the transient delta goes to very large value the solution to swing equation cannot be linearized. Hence numerical methods are used to solve the swing equation. Numerical methods are point by point method, Runga –Kutta method. The transient stability for simple machine can be determined using equal area criterion method. The transient stability for multi machine system can be carried on computer simulations. In this work transient stability is analysed using MATLAB Simulink software. Rotor angles are calculated in the transient state under different fault conditions. Critical clearing angle is defined as the maximum allowable change in the rotor angle before clearing the fault without loss of synchronism. Critical clearing time is defined as the maximum time delay that can be allowed to clear a fault without loss of synchronism.

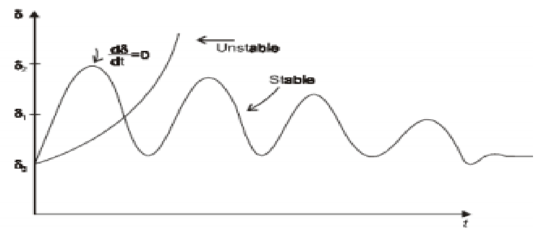

Fig 1: F1Swing curve for the synchronous machine

Critical clearing angle equation is given by

$$\delta_{cc}= \cos^{-1}\left[\frac{P_m}{P_{max}}(\delta_{max} - \delta_0) + \cos\delta_{max}\right] \quad (1)$$

Where δ_{cc}=Critical clearing angle

P_m=Mechanical power input

P_{max}=Maximum power transferred to load

δ_0=Initial rotor angle

δ_{max}=Maximum rotor angle displacement

Critical clearing time equation is given by

$$t_{cc} = \sqrt{\frac{2H(\delta_{cc} - \delta_0)}{\pi f P_m}} \quad (2)$$

Where

t_{cc}=Critical clearing time

f=Frequency

H=Inertia constant in MJ/MVA

3. DISTRIBUTED GENERATION IN POWER SYSTEM

Day by day the penetration level of DG in distribution system is increased. DG units are small scale generating units with rating of 5KW to 10MW [9].With the increasing demand for power, due to automation of every system, generation of power at far places is not recommended. And also construction of new transmission and distribution lines is not recommended, by the consideration of cost point of view. Hence go for another alternative to meet the load requirement. DG gives the best solution to meet the increased load demand. DG placed closed to load locations, the transmission and distribution lines cost reduced, voltage profile at load locations increases, transmission and distribution line losses reduced [10].

The penetration of DG in the network causes the some positive and negative impacts. With DG the direction of power is bi directional, the magnitude of fault current is increased, with the increased fault current existing protection equipment mall operate and also the transient stability of system is also decreased [11] [12] [13].by the consideration of environmental point of view DG's are made up of renewable energy sources like solar, wind, fuel cells and hydro power generation [14] in this work hydro power generation type DG is used.

4. RADIAL DISTRIBUTION NETWORK WITH HYDRO POWER GENERATION TYPE DG

Figure 2 shows the three phase balanced radial distribution network with hydro power generation is used as DG. It consists of 7 bus radial network. Grid is synchronous machine type and it is connected to the network through 132/20 KV, 30 MVA delta to star grounded transformer. And network is operated at frequency of 60 HZ. The line and load data is given in the appendix.

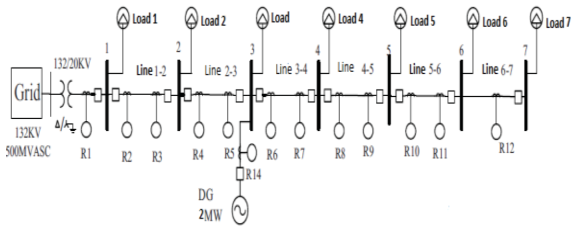

Fig 2: Single line diagram of Radial distribution network with DG

For the above radial distribution network transient stability analysis done with the measurement of rotor angles under different fault conditions like LG, LL, LLG and LLLG faults with two different power levels of DG.

Case 1: Swing curves of two machines without any fault

Figure 3 shows the rotor angles of two machines with 2 MW of hydro power generation, and it is synchronous machine interface type DG.

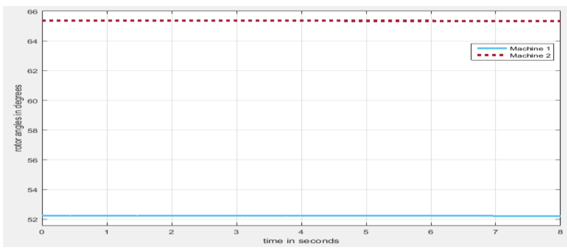

Fig 3: Rotor angles of machines without any fault with 2 MW DG

In the above waveform thick line indicates the rotor angle of machine 1 i, e grid source and it is operated at steady rotor angle of 52^0.Dottted line indicates the rotor angle of machine 2 i, e hydro power generation type 2MW DG. And DG operates at steady rotor angle of 65^0.

Figure 4 shows the rotor angles of two machines with DG as 4 MW of power generation. In the waveform thick line indicates the rotor angle of machine 1 and it is operates at 52^0.Dotted line indicates the machine 2 and it is operate at steady rotor angle of 67^0.

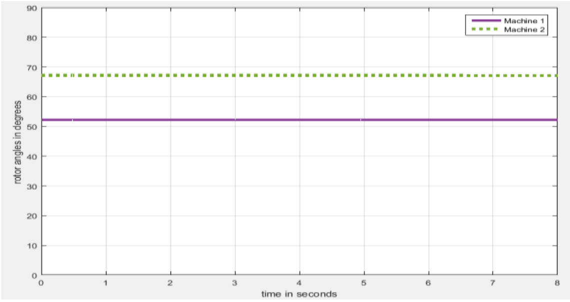

Fig 4: Rotor angles of machines without any fault with 4 MW DG

Case 2: Swing curves of machines with LG fault on line 5-6

LG fault occurred on line 5-6with fault duration of t=0.01seconds and it is transient type of fault. Running time of circuit is 60seconds and fault occurred at t=5 seconds. Without any protection equipment circuit is simulated.

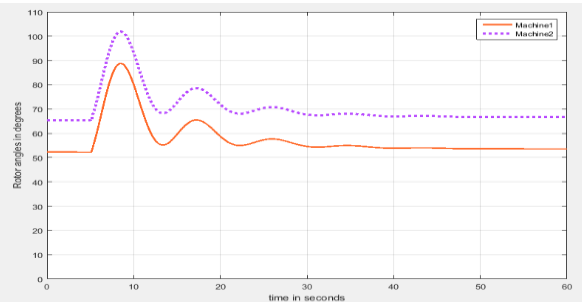

Fig 5: Rotor angles of machines under LG fault with 2 MW DG

Figure 5 shows the rotor angles of two machines under LG fault with 2 MW DG. Initially rotor angle of machine 1operate at 52^0 with LG fault in line 5-6 the rotor angle is increased to 88^0.Fault is an transient type and system is stable the rotor angle is coming to stable position and settled at steady operating angle of 54^0.Rotor angle of machine 2 operate at 65^0.LG fault occurred at line 5-6 the rotor angle is increased to 102^0. Fault is transient type and system is stable the rotor angle is coming to stable position and settled at steady operating angle of 67^0.

Figure 6 shows the rotor angle difference of two machines under LG fault with 2 MW DG.

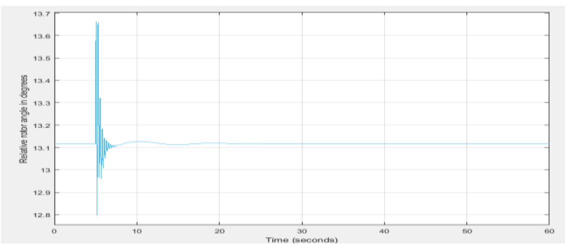

Fig 6: Rotor angle difference of machines under LG fault with 2 MW DG

The rotor angle difference of two machines is 13^0without any fault when the LG fault occurred at line 5-6 the angle is increased to 13.6^0after fault the deviation of angle is decreased to steady operating angle of 13^0.

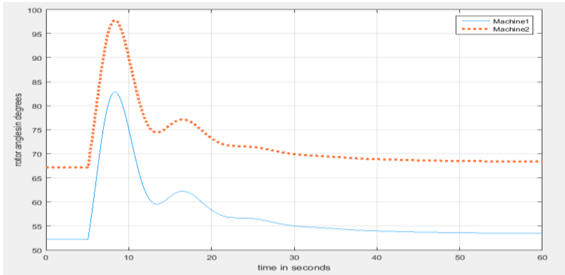

Fig 7: Rotor angles of machines under LG fault with 4 MW DG

Figure 7 shows the rotor angles of two machines under LG fault with 4 MW DG. Initially rotor angle of machine 1operate at$52^0$with LG fault in line 5-6 the rotor angle is increased to 83^0.Fault is an transient type and system is stable the rotor angle is coming to stable position and settled at steady operating angle of 54^0.Rotor angle of machine 2 operate at 67^0.LG fault occurred at line 5-6 the rotor angle is increased to 98^0. Fault is transient type and system is stable the rotor angle is coming to stable position and settled at steady operating angle of 67^0.

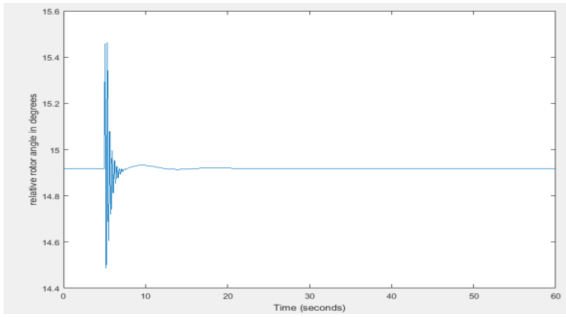

Fig 8: Rotor angle difference of machines under LG fault with 4 MW DG

The rotor angle difference of two machines is 14.9^0without any fault when the LG fault occurred at line 5-6 the angle is increased to 15.5^0after fault the deviation of angle is decreased to steady operating angle of 14.9^0.

Figure 9 shows the comparision of transient stability of two machines with 2 MW and 4 MW of hydropower generation under LG fault condition. With 2MW of DG the relative rotor angle is 13.1^0 and it is increased to 13.6^0 under LG fault condition. But with 4 MW of DG the relative rotor angle is 14.9^0 and it is increased to 15.5^0under LG fault condition. From these angles it is evident that with the increasing penetration levels of DG transient stability is decreased.

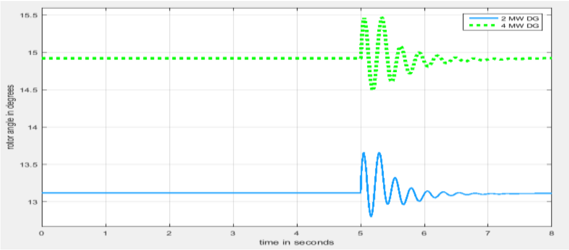

Fig 9: Comparision of Rotor angle difference of machines under LG fault with 2MW and 4MW of DG

Case 3: Swing curves of machines with LL fault on line 5-6

LL fault occurred on line 5-6with fault duration of t=0.01seconds and it is transient type of fault. Running time of circuit is 60seconds and fault occurred at t=5 seconds. Without any protection equipment circuit is simulated.

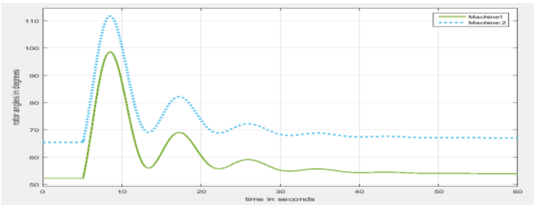

Fig 10: Rotor angles of machines under LL fault with 2 MW DG

Figure 10 shows the rotor angles of two machines under LL fault with 2 MW DG. Initially rotor angle of machine 1operate at52^{0}with LL fault in line 5-6 the rotor angle is increased to 98^0.Fault is an transient type and system is stable the rotor angle is coming to stable position and settled at steady operating angle of 54^0.Rotor angle of machine 2 operate at 65^0.LL fault occurred at line 5-6 the rotor angle is increased to 112^0. Fault is transient type and system is stable the rotor angle is coming to stable position and settled at steady operating angle of 66^0.

Figure 11 shows the rotor angle difference of two machines under LL fault with 2 MW DG.

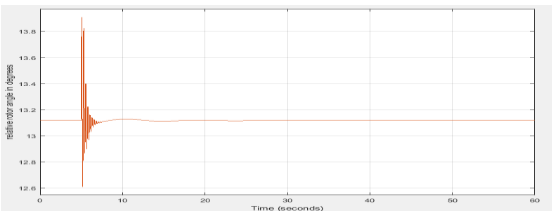

Fig 11: Rotor angle difference of machines under LL fault with 2 MW DG

The rotor angle difference of two machines is 13.1^{0}without any fault when the LL fault occurred at line 5-6 the angle is increased to 13.8^{0}after fault the deviation of angle is decreased to steady operating angle of 13.1^0.

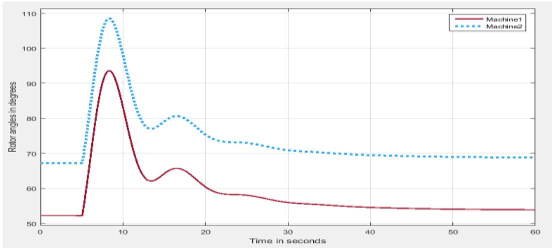

Fig 12: Rotor angles of machines under LL fault with 4 MW DG

Figure 12 shows the rotor angles of two machines under LL fault with 4 MW DG. Initially rotor angle of machine 1operate at52^{0}with LL fault in line 5-6 the rotor angle is increased to 94^0.Fault is an transient type and system is stable the rotor angle is coming to stable position and settled at steady operating angle of 54^0.Rotor angle of machine 2 operate at 67^0.LL fault occurred at line 5-6 the rotor angle is increased to 109^0. Fault is transient type and system is stable the rotor angle is coming to stable position and settled at steady operating angle of 68^0.

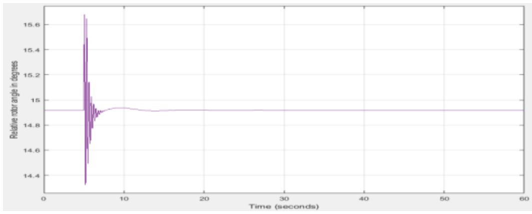

Fig 13: Rotor angle difference of machines under LL fault with 4 MW DG

The rotor angle difference of two machines is 14.9^{0}without any fault when the LL fault occurred at line 5-6 the angle is increased to 15.6^{0}after fault the deviation of angle is decreased to steady operating angle of 14.9^0.

Figure 14 shows the comparision of transient stability of two machines with 2 MW and 4 MW of hydropower generation under LL fault condition. With 2MW of DG the relative rotor angle is 13.1^0 and it is increased to 13.8^{0}under LL fault condition. But with 4 MW of DG the relative rotor angle is 14.9^0 and it is increased to 15.6^{0}under LL fault condition. From these angles it is evident that with the increasing penetration levels of DG transient stability is decreased.

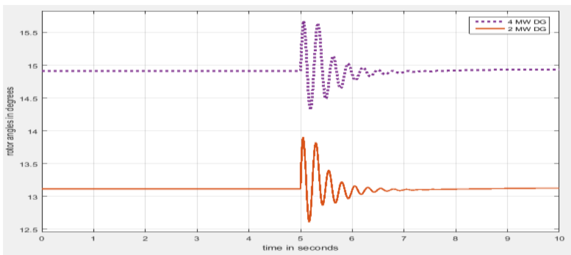

Fig 14: Comparision of Rotor angle difference of machines under LL fault with 2MW and 4MW of DG

Case 4: Swing curves of machines with LLG fault on line 5-6

LLG fault occurred on line 5-6with fault duration of t=0.01seconds and it is transient type of fault. Running time of circuit is 60seconds and fault occurred at t=5 seconds. Without any protection equipment circuit is simulated.

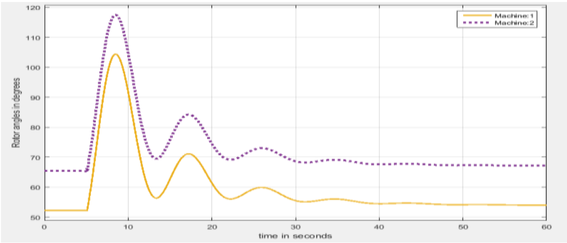

Fig 15: Rotor angles of machines under LLG fault with 2 MW DG

Figure 15 shows the rotor angles of two machines under LLG fault with 2 MW DG. Initially rotor angle of machine 1operate at52^{0}with LLG fault in line 5-6 the rotor angle is increased to 104^0.Fault is transient type and system is stable the rotor angle is coming to stable position and settled at steady operating angle of 54^0.Rotor angle of machine 2 operate at 65^0.LL fault occurred at line 5-6 the rotor angle is increased to 117^0. Fault is transient type and system is stable the rotor angle is coming to stable position and settled at steady operating angle of 67^0.

Figure 16 shows the rotor angle difference of two machines under LLG fault with 2 MW DG.

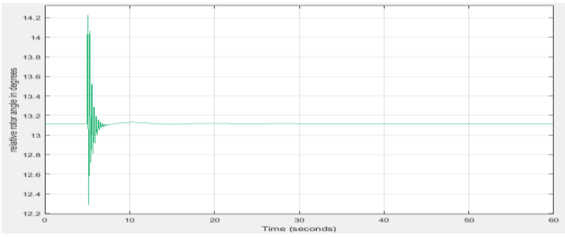

Fig 16: Rotor angle difference of machines under LLG fault with 2 MW DG

The rotor angle difference of two machines is 13^{0}without any fault when the LLG fault occurred at line 5-6 the angle is increased to 14.2^{0}after fault the deviation of angle is decreased to steady operating angle of 13.1^0.

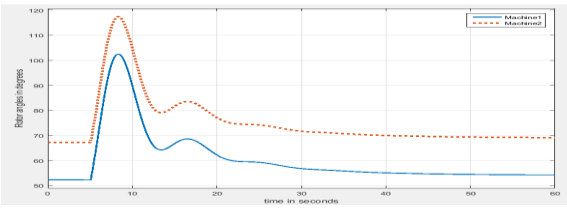

Fig 17: Rotor angles of machines under LLG fault with 4 MW DG

Figure 17 shows the rotor angles of two machines under LLG fault with 4 MW DG. Initially rotor angle of machine 1operate at52^{0}with LLG fault in line 5-6 the rotor angle is increased to 103^0.Fault is transient type and system is stable the rotor angle is coming to stable position and settled at steady operating angle of 54^0.Rotor angle of machine 2 operate at 67^0.LLG fault occurred at line 5-6 the rotor angle is increased to 117^0. Fault is transient type and system is stable the rotor angle is coming to stable position and settled at steady operating angle of 68^0.

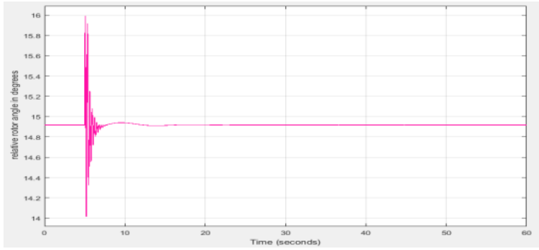

Fig 18: Rotor angle difference of machines under LLG fault with 4 MW DG

The rotor angle difference of two machines is 14.9^{0}without any fault, when the LLG fault occurred at line 5-6 the angle is increased to 16^{0}after fault the deviation of angle is decreased to steady operating angle of 14.9^0.

Figure 19 shows the comparision of transient stability of two machines with 2 MW and 4 MW of hydropower generation under LLG fault condition. With 2MW of DG the relative rotor angle is 13.1^0 and it is increased to 14.2^{0}under LLG fault condition. But with 4 MW of DG the relative rotor angle is 14.9^0 and it is increased to 16^{0}under LLG fault condition. From these angles it is evident that with the increasing penetration levels of DG transient stability is decreased.

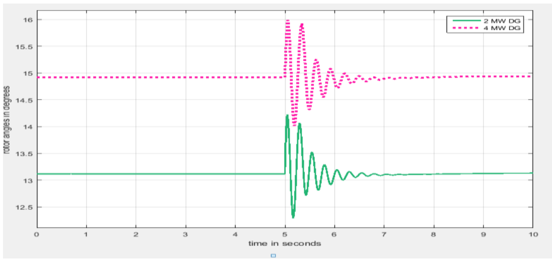

Fig 19: Comparision of Rotor angle difference of machines under LLG fault with 2MW and 4MW of DG

Case 5: Swing curves of machines with LLLG fault on line 5-6

LLLG fault occurred on line 5-6with fault duration of t=0.01seconds and it is transient type of fault. Running time of circuit is 60seconds and fault occurred at t=5 seconds. Without any protection equipment circuit is simulated.

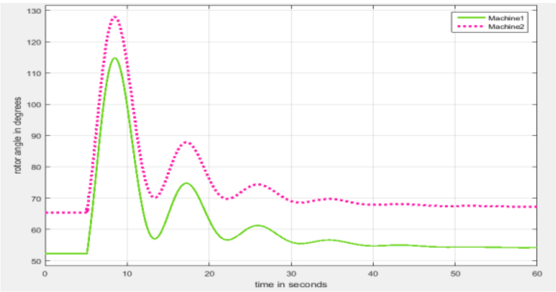

Fig 20: Rotor angles of machines under LLG fault with 2 MW DG

Figure 20 shows the rotor angles of two machines under LLLG fault with 2 MW DG. Initially rotor angle of machine 1operate at$52^0$with LLLG fault in line 5-6 the rotor angle is increased to 115^0.Fault is transient type and system is stable the rotor angle is coming to stable position and settled at steady operating angle of 54^0.Rotor angle of machine 2 operate at 65^0.LLLG fault occurred at line 5-6 the rotor angle is increased to 127^0. Fault is transient type and system is stable the rotor angle is coming to stable position and settled at steady operating angle of 67^0.Figure 21 shows the rotor angle difference of two machines under LLLG fault with 2 MW DG.

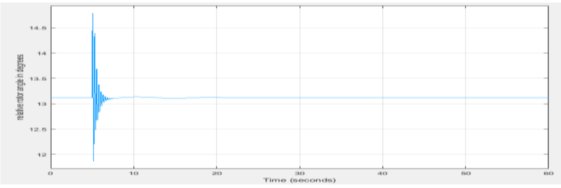

Fig 21: Rotor angle difference of machines under LLLG fault with 2 MW DG

The rotor angle difference of two machines is 13.1^0without any fault, when the LLLG fault occurred at line 5-6 the angle is increased to 14.5^0after fault the deviation of angle is decreased to steady operating angle of 13.1^0.

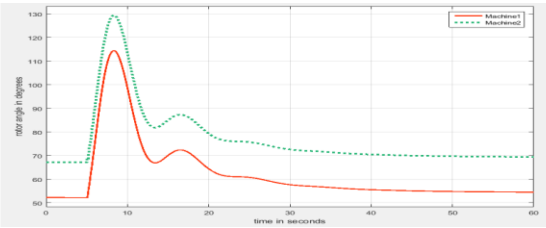

Fig 22: Rotor angles of machines under LLLG fault with 4 MW DG

Figure 22 shows the rotor angles of two machines under LLLG fault with 4 MW DG. Initially rotor angle of machine 1operate at$52^0$with LLLG fault in line 5-6 the rotor angle is increased to 115^0.Fault is an transient type and system is stable the rotor angle is coming to stable position and settled at steady operating angle of 54^0.Rotor angle of machine 2 operate at 67^0.LLG fault occurred at line 5-6 the rotor angle is increased to 130^0.

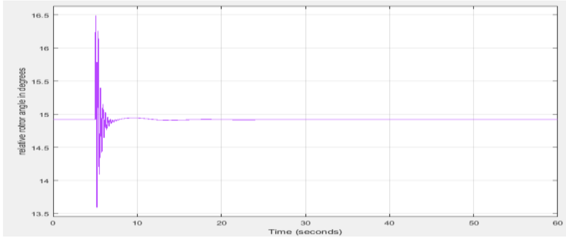

Fig 23: Rotor angle difference of machines under LLLG fault with 4 MW DG

The rotor angle difference of two machines is 14.9^0without any fault when the LLLG fault occurred at line 5-6 the angle is increased to 16.5^0after fault the deviation of angle is decreased to steady operating angle of 14.9^0.

Figure 24 shows the comparision of transient stability of two machines with 2 MW and 4 MW of hydropower generation under LLLG fault condition. With 2MW of DG the relative rotor angle is 13.1^0 and it is increased to 14.5^0under LLLG fault condition. But with 4 MW of DG the relative rotor angle is 14.9^0 and it is increased to 16.5^0under LLLG fault condition. From these angles it is evident that with the increasing penetration levels of DG transient stability is decreased.

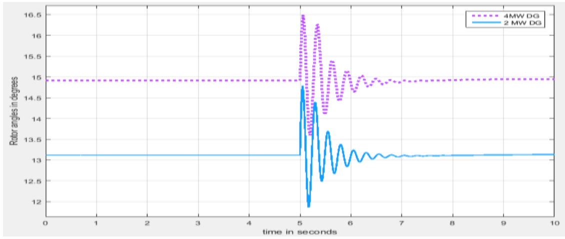

Fig 24: Comparision of Rotor angle difference of machines under LLLG fault with 2MW and 4MW of DG

Table 1

Comparision of rotor angles of two machines under different fault conditions

Type of fault	2 MW			4 MW		
	δ_1	δ_2	δ_{12}	δ_1	δ_2	δ_{12}
Without fault	52^0	65^0	13.1^0	52^0	67^0	14.9^0
LG	88^0	102^0	13.6^0	83^0	98^0	15.5^0
LL	98^0	112^0	13.8^0	94^0	109^0	15.6^0
LLG	104^0	117^0	14.2^0	103^0	117^0	16^0
LLLG	115^0	127^0	14.5^0	115^0	130^0	16.5^0

By comparing the above two different power levels of DG with the increased power level of DG the transient stability is decreased.

5. APPENDIX

Table 2 line data

Line id	R(Ohms)	L(H)
Line 1-2	0.0799	0.004917
Line 2-3	0.1143	0.005533
Line 3-4	0.196	0.0028117
Line 4-5	0.342	0.003050
Line 5-6	0.668	0.003395
Line 6-7	0.668	0.001697

Table 3 Load data

Load id	P(MW)	Q(MW)
Load 1	1.61	0.99
Load 2	0.87	0.5626
Load 3	1.5867	0.9414
Load4	1.99	1.394
Load 5	1.4259	0.9582
Load 6	0.6934	0.3742
Load 7	0.9792	0.606

6. CONCLUSION

A hydro power DG of each 2MW and 4MW one at a time is used in simulation study of distribution system. With the integration of hydro DG total number of synchronous machines in the system increased from one to two. The transient stability study was conducted to the system by creating one fault at a time from the list of LG, LL, LLG, and LLLG faults. The rotor angle difference of two machines with 2 MW hydro power DG is 13.1^0 without any fault to the network.But with the increasing penetration levels of hydro power DG to 4 MW the rotor angle difference of two machines is 14.9^0 without any fault. With the increased power level of DG to the network causes the increased in the rotor angle difference of two machines. The transient stability of the system is decreased with increasing penetration level of DG to the network. In this work mainly focused on the three phase balanced radial distribution network. The transient stability is calculated to the network with rotor angle displacements of the network under various fault conditions like LG, LL, LLG and LLLG faults with two different power levels of DG. Among all the faults three phase to ground fault gives the maximum rotor angle displacement from its steady operating position. With the increased power level of DG transient stability decreased.

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