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Stability Enhancement of Micro-Grid Using Fuzzy Logic Controller In Coordination With SMES, SFCL And Distributed Generation Units

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Abstract: Now days, the contribution for Stability of a micro-grid under fault conditions is very important. In order to enhance the stability of micro- grids, this paper proposes fuzzy logic controller in coordination with SMES, SFCL and Distributed generation units. This coordination control smoothly separate the micro-grid from main network in case of severe faultsand assist the micro-grid to achieve the faultridethrough(FRT) when the faults are minor faults. In this paper, the fuzzy logic controller is used which is more accurate than any other conventional controllers. The details of modelling, architecture and control strategy are presented. The simulation analysis of micro-grid along with fuzzy logic controller, SMES, SFCL and distributed generation units is implemented in MATLAB. Pertaining to the performance interpretationof coordination control for severe and minor faults and the output results confirm the robustness and effectiveness of the coordination control.

KEY WORDS- Coordination control, fuzzy logic controller, distributed generation, micro-grid, super conducting fault current limiter(SFCL) super conducting magnetic energy storage(SMES)

INTRODUCTION:

Distributed energy resources (DER), such as distributed generation and distributed storage are sources of energy located near local loads and can provide a variety of benefits counting improved reliability, effectiveness if properly operated under the faults conditions in the electrical distribution system. In commendations to the use of superconducting power devices, SMES and SFCL are two great potentials devices for the power system stability in the electric power systems. SMES and SFCL can be expanded both in high-voltage main networks and low-voltage micro-grids which are normally to accommodate and maximize the utilization of distributed generation units. For the continuous increasing penetration levels and power exchanges, it is crucial to guarantee the high penetration stability of a micro-grid, peculiarly under short-circuit fault conditions. Under the severe fault conditions, the micro-grid should transfer to the island mode and some critical challenges existing for the micro-grid's balanced operation, like low system inertia to deal with the power unbalance in the micro-grids. Accordingly it is crucial to maintain effective voltage and frequency regulation of that micro-grid operates in the island mode, or else, the deflections in the micro-grid's voltage and frequency may be out of the tolerance rang along with the increasing power unbalance.

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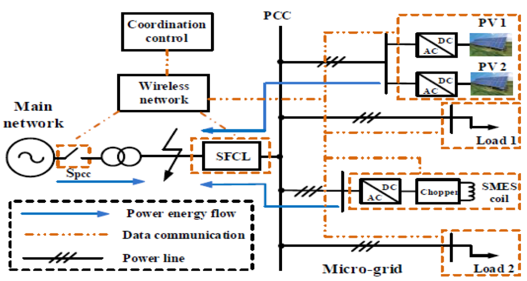

FIGURE1.**Representation of Micro-gridin coordinationwith SMES, active SFCL and distributed generation units.**

Due to this, power unbalance in the micro-grids, a superconducting power devices such as SFCL to empower the fault current limit and mitigate the voltage sag when the micro-grid is under the progress of the mode transfer, and after the island mode is being achieved the fault current surge can be decreased, and improving process of micro-grid voltage may be increased. In addition, using SMES for the micro-grid is to offer consequent active and reactive power compensation which can provide references of voltage and frequency for stabilizing the micro-grid's performances. So, by taking the advantage strengths of SMES and SFCL could provide better micro-grid control capability.

For literature review on the micro-grid's stability and the coordination use of SMES, SFCL is shown below. In [1], [2], stability indexes which are clearing time, frequency grid code violation time, small signal stability analysis are performed for micro-grid. In[3], [4], for stability development FRT control strategy, low-pass based damping method are given, but the performances of these two are depends on converters capability.

In figure 1, the micro-grid consists of coordination control of SMES, active SFCL, fuzzy logic controller, solar PV generators, two static power loads.

SMES MODELING AND CONTROL

From all other energy storage devices, the SMES has following technical advantages such as high efficiency, fastness, high energy density, controllability, unlimited charging, discharging cycles and this SMES controls the constant power flow at PCC, voltage and frequency of the micro-grid[5],[6],[7].

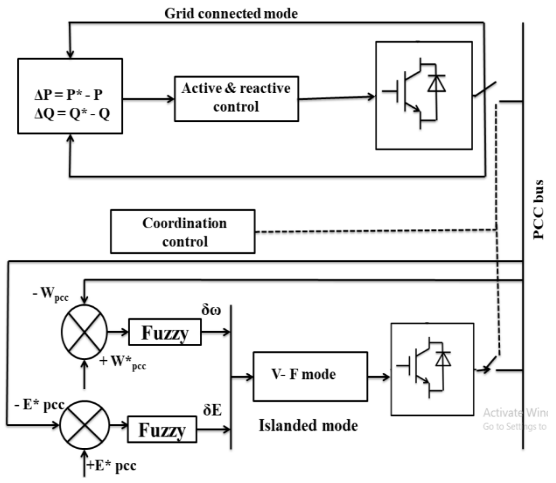

FIGURE **2(a)Control block design of SMES**

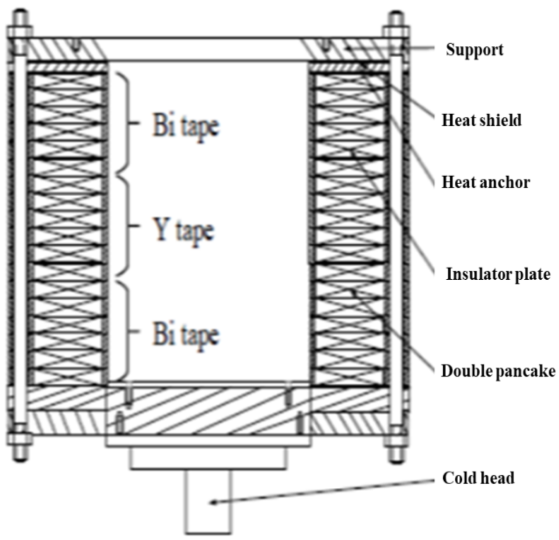

FIGURE **2(b)Representation of the superconducting magnet**

The figure 2 represents the micro-grid connected to the network which operates active and reactive power control for power tracking [8]. Figure 2(a), coordinate control between P-Q and the V-F modes. Figure 2(b) structural diagram of the superconducting magnet.

Active SFCL MODELING AND CONTROL

The schematic diagram of SFCL is shown in the below figure 3 (a) which consists of air-core superconducting transformer, LC filter, pulse width modulation. In SFCL, I_2 current is controlled by using converters in the air-core transformer. The selection of current limiting mode is done by coordinated control centre and the results to the

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converter controller which has both outer voltage control loop & inner current loop. The pulse signals after a series of computations send to drive the pulse width modulation converter.

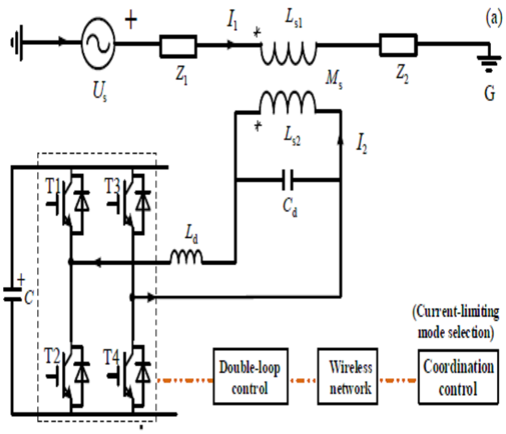
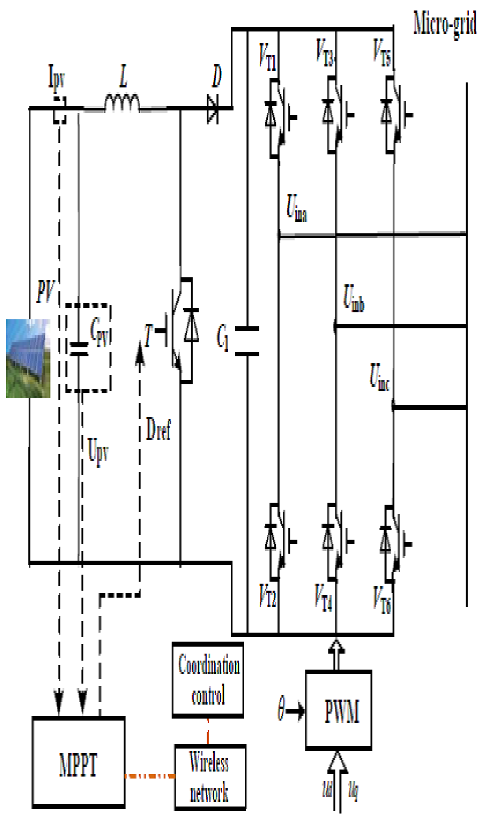


FIGURE 3 (a) **Voltage compensation model active SFCL**

Active SFCL has (1) high controllability, flexibility, owns several current limiting modes and these current limiting requirements for flexible impedance control. Earlier the micro-grid separated from Point of common coupling it decreases the fault current and voltage compensation. (2) Applicable for various voltages, greater linearity for SFCL impedance and avoids the saturation in the air-core transformer.

PV GENERATION UNIT CONFIGURATION



FI

GURE **4 Grid connected PV generation unit**

The structural representation of micro-grid connected PV generation units is shown in the figure 4. During the normal conditions, the boost converter accepts the MPP control to assure the efficiency of PV unit. Transistors V_{T1}-V_{T6} for insulated bipolar transistors.

Under short-circuit faults in the micro-grid, the renewable energy sources affected by the voltage drops. At this short circuit fault, the grid power is decreased and the DC/DC converter transmits maximum power into the DC link from PV generation unit.

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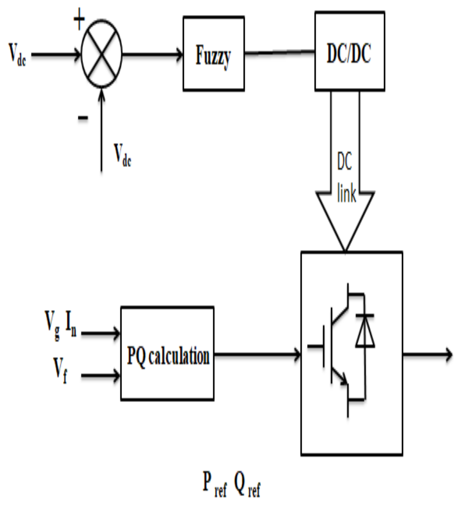

FIGURE **5 Control block design of VSC of the PV unit**

COORDINATION PRINCIPLES OF SFCL, SMES AND PV

The basic coordination principle for micro-grid with respect to SMES, SFCL and PV are determined below

Under severe or permanent fault conditions, the micro-grid is divided from the main network as it lose stable power exchange and the coordination centre divided micro-grid safely and reliably.

Based on the fault conditions, the coordination control activates SMES P-Q control to V-F control and SFCL for current limiting mode driven. The distributed generation units act as voltage frequency regulation.

During minor/temporary faults, the fault ride through are realized by the micro-grid for power support if voltage dips is within the limits. When the fault increases from minor faults, the coordinated centre allows SMES in its original and SFCL for fault current limiting (mode1) and the distributed generation units at MPP control.

The given/proposed stability enhancement of micro-grid in coordination with SMES, SFCL and distributed generation units using fuzzy logic controller are systematically taken into account. Whatever the fault conditions, these coordination control of SMES, SFCL and Distributed generation units using fuzzy logic controller supply power in stable and transient process. For severe faults, the micro-grid is separated before the faults and the transient process shows in time range after the faults. For minor/temporary faults, the time range of fault ride through is shown by transient process.

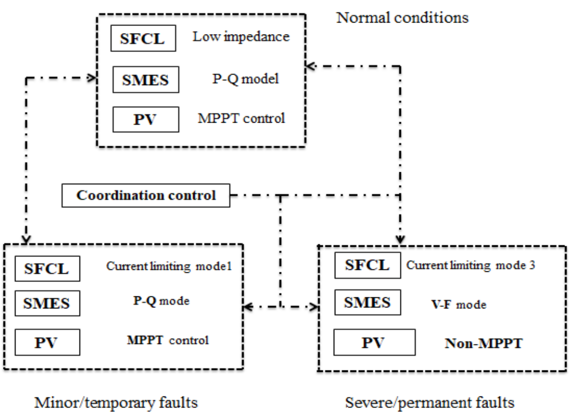

FIGURE **6.Switching control for different faults conditions**

For different fault conditions, different switching control principles are shown in the given below figure 6. For Normal and Minor/temporary faults similar control switching principles only SFCL changed from impedance. For severe fault conditions, MPPT to non-MPPT and SMES is in V-F mode.

SIMULATION STUDY

Micro-grid in coordination with SFCL, SMES and distributed generation units using fuzzy logic controller Simulink model developed in MATLAB and the required parameters are shown below Table I

TABLE I

PARAMETERS FOR THE SIMULATION MODEL

Micro-grid with SMES, SFCL and distributed generations units	
PV1 /PV2	150 kW/80 kW
Power Line	0.27+j0.347 Ω/km, 2 km
Nominal load 1/ 2	60 kw/ 40 kw
Nominal voltage/ frequency	10 kV/ 50Hz
SMES magnet	150 kJ/ 100 kW
SMES chopper	800 V / 5000uF
Active SFCL	L_{s1}=80 mH, L_{s2}=80mH, M_s=72

Under normal conditions, PV_1/PV_2 are in P-Q for maximum output. If severe faults occur, the MPP changed into non-MPP for self-protection and

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involved in power regulation. The static power model is resistor model in simulation and the power equation is

$P_{load}= 3U^2R$

U = phase voltage over resistor element

R = resistance of resistor element

SMES uses VSC and chopper from Simulink library and super conducting magnets is shown as a non-resistive inductance type[36]. For SFCL, air-core transformer is as a non-resistive transformer and VSC with DC capacitor for converter.

The parameters for SMES and SFCL are given below Tables II and III respectively.

TABLE II

SMES Magnet specifications

Structure parameters		Operation parameters	
Magnet height	210.6mm	Magnet voltage	800 V
Coil number	18	Magnet current	165 A
Inner coil	240 mm	Operation temperature	20K
Outer diameter	396 mm	Magnet inductance	11.2 H

TABLE III

Specifications of super conducting transformer used in SFCL

Structure parameters		Operation parameters	
Structure type	solenoid pancakes	Max-compensating voltage	5 kV
HTS tape	YBCO	Critical current	130 A
Tape width/thickness	8mm/0.096mm	Operation temperature	77 K
Critical temperature	200 A		
Inner diameter	88 mm	Current- limiting ratio	0.5
Outer diameter	154 mm	Coupling factor	0.9

SIMULATION RESULTS

Normal conditions:

Under normal conditions, the simulation results for Distributed power generation, PCC voltage and P_{load} is given below figures 7-8. SMES maintains 250 kW power exchange level and active SFCL in the micro-grid doesn't operate. If the output power is greater than the required local load then the power flows from grid to the main network.

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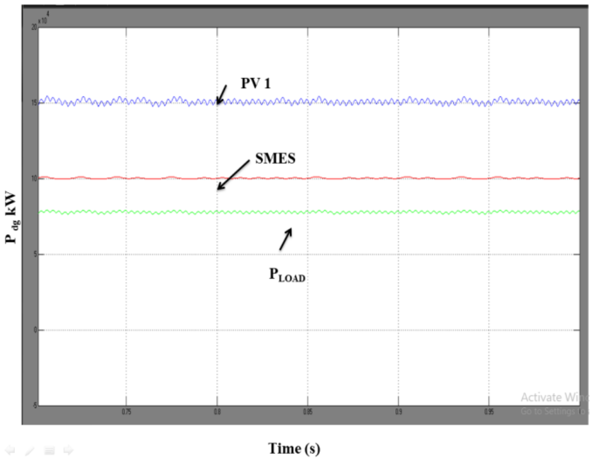

FIGURE 7 **(a) P $_{DG}$Under normal conditions**

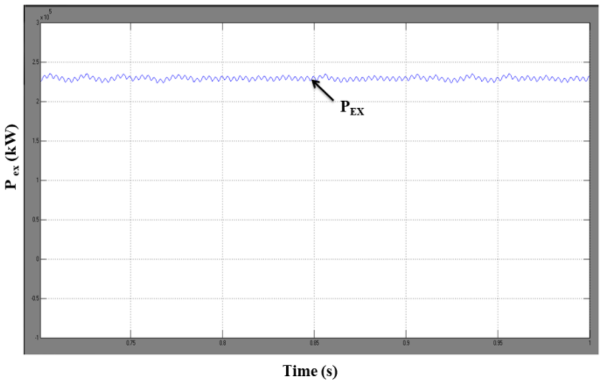

FIGURE 7**(b)Exchange power (P_{ex}) under normal conditions**

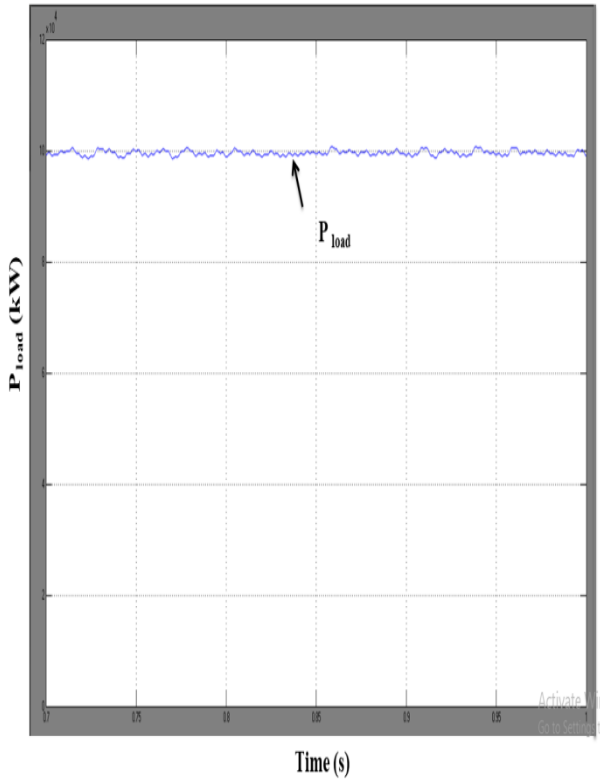

FIGURE 7 **(c) Load power under normal conditions**

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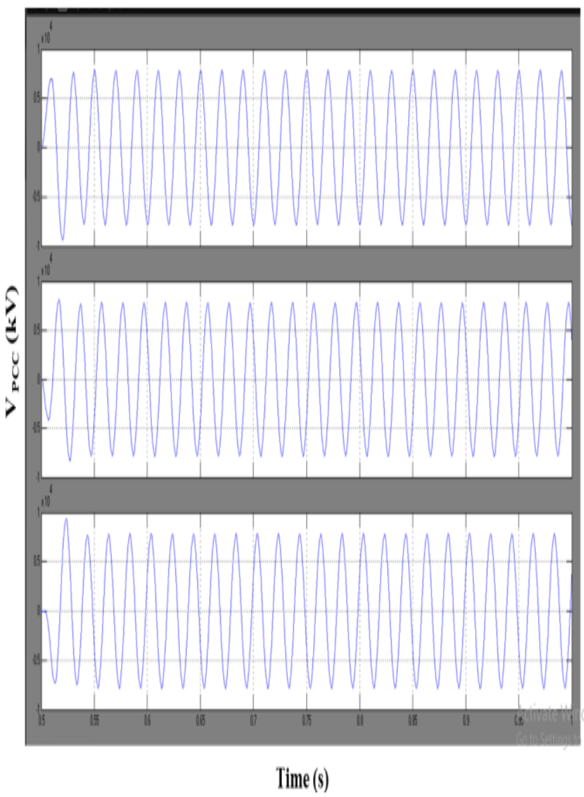

FIGURE 8 **Three phase voltage at PCC in the micro-grid under normal conditions**

Severe fault conditions:

During severe fault conditions, the simulation results for the micro-grid connected coordination control are shown bin below figures 9-10. After the fault occurs, the PCC opened at 120ms and the grid is in islanded mode. If there is no coordination control in the micro-grid, the grid itself resists the faults conditions. SFCL not operated and SMES is in V-F mode till PCC finishes separation from the grid. The PV is running at high MPPT and very high power imbalance.

In coordination control, the SMES and active SFCL play parallel roles and the PV reduces output power by adopting non-MPPT for protecting generation units. In islanded mode of the micro-grid, the SMES is in V-F control for V-F stabilization, but the SMES alone not stabilize the voltage and frequency. So, the voltage at PCC is increased 1.28 times from nominal value. The load power increased from 100 kW to 166 kW. So, the distributed generation units have 166 kW for stable operation. The micro-grid is in islanded mode for very short duration in which the power at load is recovered before this short time.

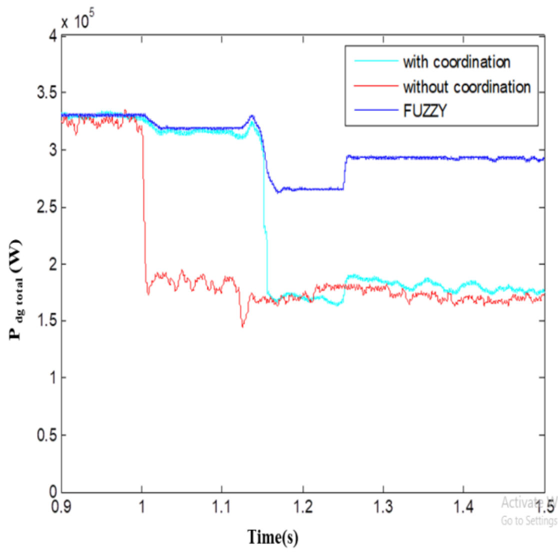

FIGURE **9(a) Total distributed generation power at severe fault**

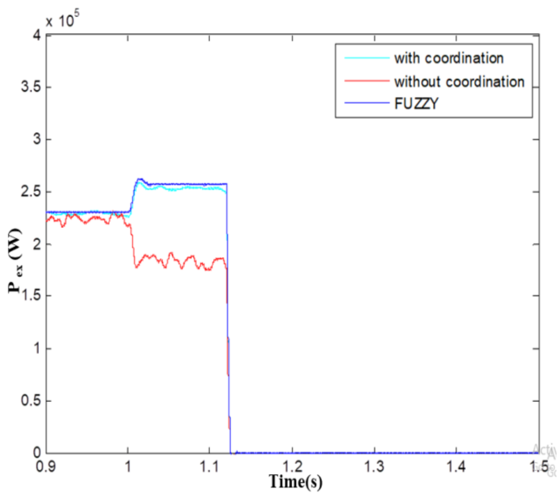

FIGURE **9(b) Exchange power at severe fault**

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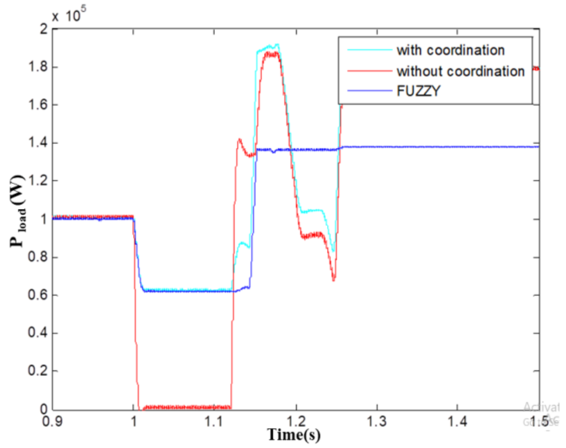

FIGURE **9(c) Load power at severe fault**

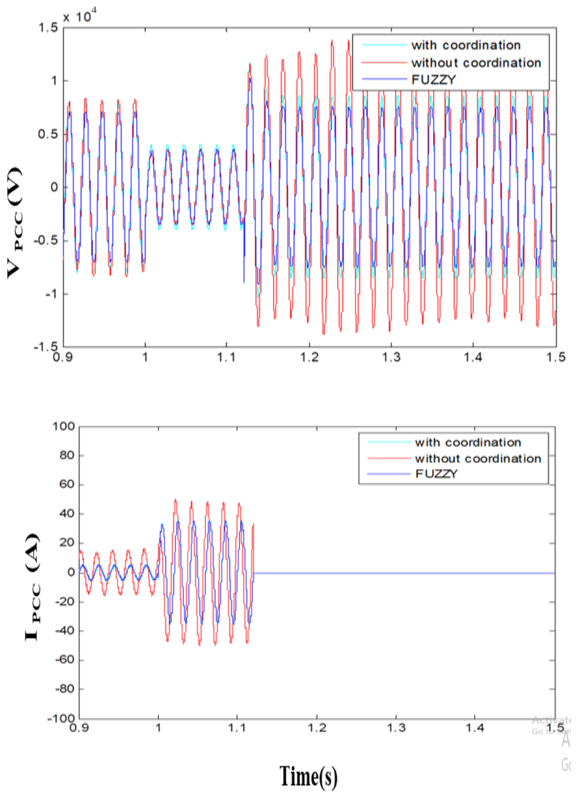

FIGURE **10 PCC Voltage and current at severe faults**

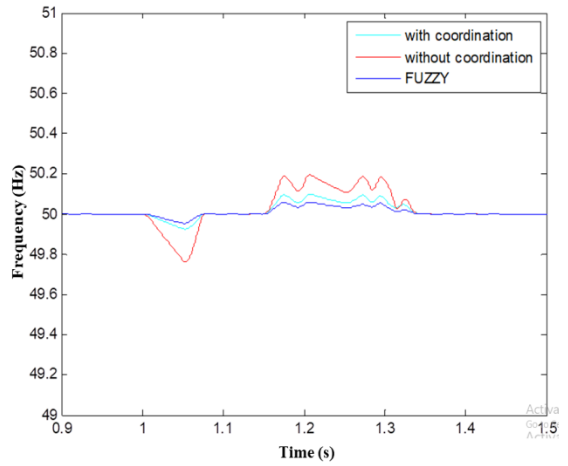

FIGURE **10 (b) Frequency at severe fault**

Minor fault conditions

In case of minor faults, the increased fault resistance and time is taken as t= 1s and R_g =5Ω. These minor fault is removed after 120 ms. The figure 11 gives he simulation results. The coordination center aids micro-grid for FRT operation. If the critical fault resistance is present then the sever fault conditio is applied in order to reduce the critical fault resistance

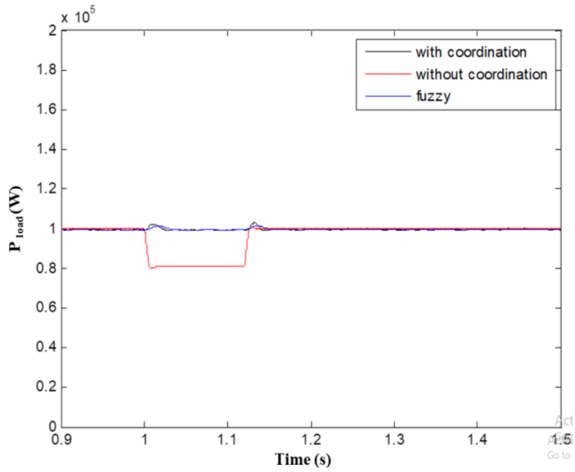

FIGURE **11(a) Load power under minor fault**

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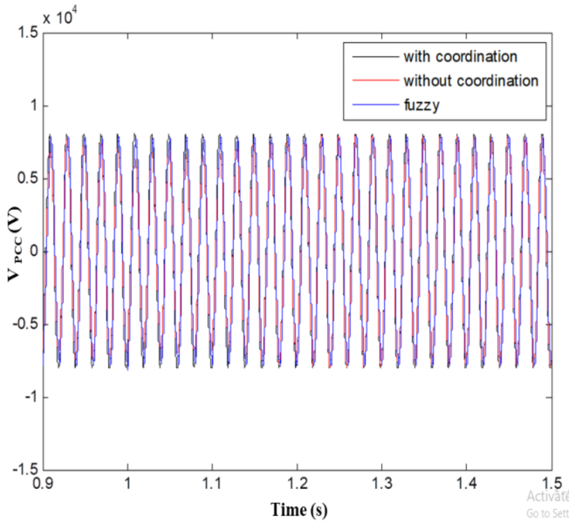

FIGURE **11 (b) PCC voltage at minor fault**

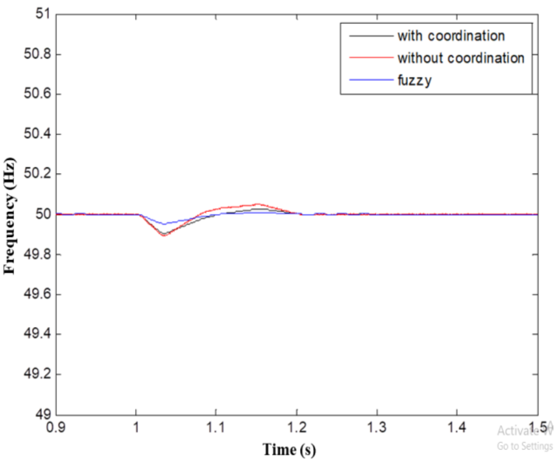

FIGURE **11 (c) Frequency at minor fault**

CONCLUSION

For stability improvement in the micro-grid under different fault conditions, the proposed method has been implemented successfully. It was found that the stable power exchange under severe and minor fault conditons through the coordinatin control of active SFCL, SMES, and distributed generation units for micro-grid stability. The fuzzy logic controller proves its fastness and robustness in the coordination control method. This coordination control using fuzzy is suitable for large micro-grids and other control structures.

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