Centralized Multi-agent Self-healing Power System with Super Conducting Fault Current Limiter

Sujil A
Department of Electrical Engineering
Malaviya national institute of Technology
Jaipur, Rajasthan, India-302017
sujilavijayan@gmail.com

Saurabh Kumar Agrwal
Department of Computer Engineering
Malaviya national institute of Technology
Jaipur, Rajasthan, India-302017
saurabhagarwal1331@gmail.com

Rajesh Kumar
Department of Electrical Engineering
Malaviya national institute of Technology
Jaipur, Rajasthan, India-302017
rkumar.ee@gmail.com

***Abstract*—The promotion of recent self-healing power system research has been directed towards centralized commands and control functions. This paper presents a self-healing power system using multi agent system (MAS) with superconducting fault current limiter. For a complex power system comprised of numerous micro grids, it is potentially unrealistic to expect that centralising total system control function is feasible. Therefore, in this paper particularly interested in making online decision by utilizing smart micro-grid control agents that cooperate during normal and fault situations. Control decision is being taken mutually by agents as these agents exchange circuit information between each other. Day by day increase in power generation capacity of electrical power systems has leads to increase in fault current level which can exceed the maximum designed short-circuit rating of the switch gear. The conventional devices used for the fault current have a responds time delay that can pass initial two to three fault current cycles through it before getting activated. Super Conducting Fault Current Limiter (SFCL) is innovative electric equipment which has the capability to limit fault current within first cycle of the fault current. However, a shortage of research concerning the implementation of SFCL with Multi-agent system in micro grid is felt. The centralized multi-agent system with SFCL explored in this paper help to support an enabling technology of future self-healing power system.**

***Index Terms*—Multi Agent System, Fault current limiter, Resistive SFCL, Smart grid, Self-healing.**

I. Introduction

Smart grid is the modern technology used for future power grid which integrates the modern communication technology and renewable energy resources for the 21st century power grid in order to supply electric power which is cleaner, reliable, resilient and responsive than conventional power system [1]. Micro grids are sub set of electric power system, having distributed generation sources (DG) connected with them. These micro grids may or may not be connected with conventional power grid according to their modes of operation, but the need to integrate various kinds of DGs and loads with safety should be satisfied. However, newly emerging problems due to these integrations are also of severe nature and needs to be taken care of. Two major challenges expected by direct connection of DGs with the power gridare the excessive increase in fault current and the islanding issue which is caused when, despite a fault in the power grid, DG keeps on providing power to fault-state network.

The capability of a system to automatically detect and recover functionality when faced with a single or many casualty events called self-healing. In the contest of power system, this definition is somewhat refined to include the rapid identification of problems, actions to minimize any adverse impacts from casualties, and the prompt recovery of the system to a stable operating state [2, 3]. Emergency reaction stage and restorative stage are the two distinct stages of the self-healing. During the emergency stage fault condition is detected and the system reacts to reduce it typically by isolation. Many emergency reactions may be automatic or predetermined, but have the effect of placing the system in a safer, less hazardous condition. Once the system overcomes the initial emergency, restoration can begin. During restoration, a series of reconfigurations may take place improving overall system condition, involving breaker manipulations, generation startup or shutdown, load shedding or pickup, or other actions that change system operational posture. The restoration stage may be both a longer and more complicated self-healing stage, requiring more complex decisions. Typical performance measures of self-healing may include the quantity of components that remain energized.

Conventional protection device installed for the protection of excessive fault current in electric power systems especially at the high voltage substation level, are the circuit breaker tripped by over current protection relay which has a responds time delay that allows initial two or three fault current cycle to pass through before getting activated [4].Super conducting fault current limiter is a lengthy super conductor wire inserted in series with transmission line or distribution feeder to limit fault current abruptly increasing resistance.The SFCL can limit fault current within first cycle of the fault current The first cycle suppression of fault current by SFCL results in an increased transient stability of power system carrying higher power with greater stability[5,6].

Up to now, there were some research activities discussing the fault current issues of smart grid and superconducting fault current limiters for smart grid applications [7,8]. But the super conducting fault current limiters with the Multi agent system into micro grid was not found yet. Hence, solving the problem of increasing fault current in micro grids by using multi agent based SFCL technology is the main concern of this work. In this paper, performance of multi agent based SFCL and its effects on fault current with and without SFCL was investigated by considering typical smart grid model

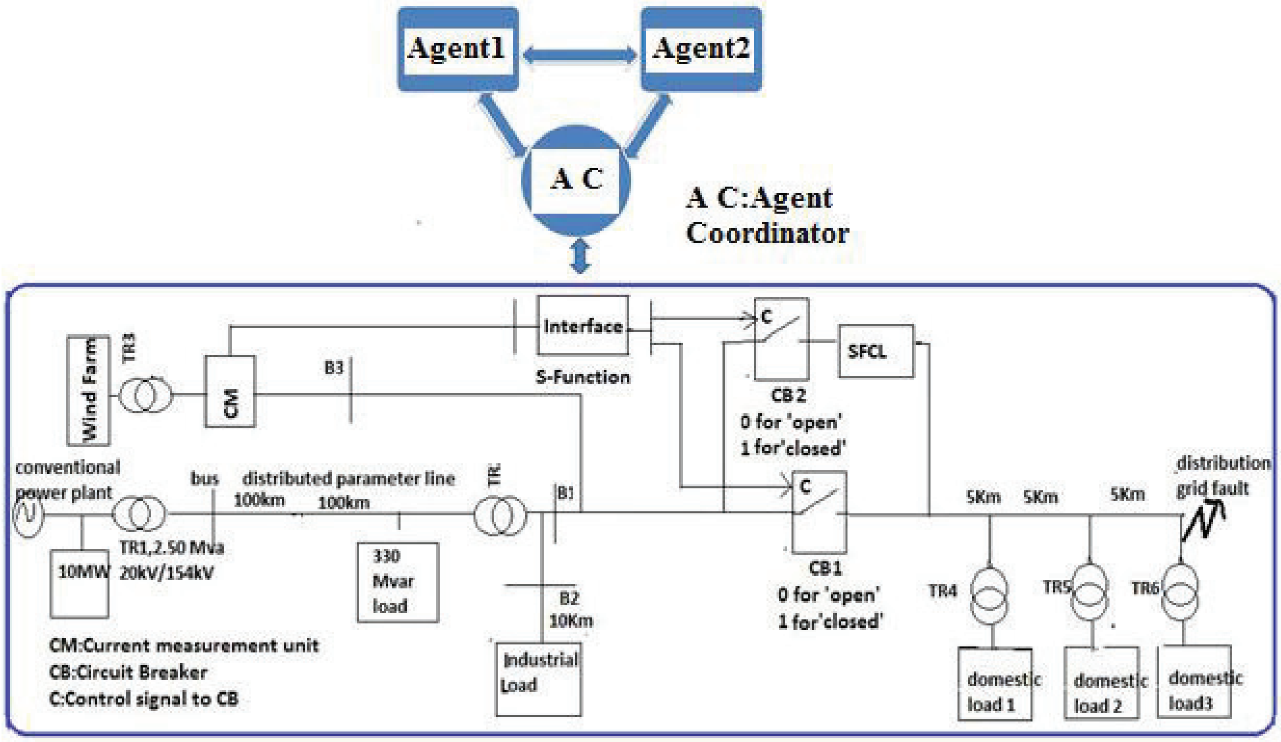

Fig. 1. Single line diagram of Power system model designed in Simulink/Sim Power System and interfacing with Agent system

including generation, transmission and distribution network with dispersed energy resource (wind farm).

This paper elaborates multi agent system to detect the abnormalities in the power system (i.e. fault) and sends the control signal to the circuit breaker accordingly reduce the fault current by using super conducting fault current limiter. Agents are being deployed in system and detect fault using centralized multi-agent planning as shown in Figure 1. In centralized multi-agent planning [9] a coordinator agent analysis planning of an individual agent and identify possible inconsistencies and conflicting interactions, like conflicts between agents over limited resources. The coordinator agent than tries to modify planning of each agent. Further coordinator agent combines these partial planning into a multi-agent planning.

This paper is further organised as follows: section 2 defines multi agent system, advantages of multi agent system, multi agent system design, agent platform and proposed multi agent system for smart grid. Section 3 presents the power system model developed in Matlab including generation, transmission and distribution with wind farm as dispersed energy resource. This section also explains the modelling of SFCL. Section 4 describes the case study and the result and discussion after the successful implementation of proposed multi agent system. Section 5 concludes that with the help a centralised multi-agent system and SFCL can give a self-healing power system.

II. Multi-Agent System(MAS)

A multi-agent system is the collection of several agents interacting with each other. A computational entity that operate without human intervention (Autonomous), interact with each other (sociality), perceive and react to their environment (reactivity), exhibit goal-oriented behaviour by taking initiatives (pro-activity) are called agents[10].

A. Advantages of MAS

The multi agent system has following advantages:

- *Extesibility :* number of agents working on a problem can be altered.
- *Robustness:* ability to tolerate uncertainty due to the suitable information exchanged among agents.
- *Maintainability:* It is easy to maintain multiple components-agents because of its modularity.
- *Flexibility:* Agents with different abilities can adaptively organize to solve the current problem.
- *Learning of agents:* Agents update their rules to provide better performance
- *Reuse:* Functionally specific agents can be reused in different agent teams to solve different problems.

B. MAS Design

A lot of methodologies are available in literature for a multi agent system [11-13] but their fundamentals are same and their fundamentals are same. By developing or extending traditional software engineering approaches and knowledge engineering approaches, the design methodologies have emerged for the specification and design of multi-agent systems. Generally there are three phases for the design of a multi agent system i.e. conceptualization, analysis and design. The problem to be solved is specified in the conceptualization phase, analyzed in the analysis phase and the results from the analysis phase are used to produce agents and their communication strategy.Figure 2 shows the typical stages of multi agent design.

In design process the output from the each stage is used in the subsequent stages. This methodology begins with system requirement specification and capturing of knowledge to fulfil those requirements. During task decomposition stage, the specified requirement and captures knowledge are transformed in to hierarchy of tasks and sub tasks. Next stage is the designed vocabulary of agent communication called ontology. Modelling of agent uses the task hierarchy and ontology to identify a group of autonomous agents with the abilities to perform the tasks. The outcome of this stage is a set of agents and specific tasks that the agents should perform. After the agent modelling the agent interaction must be defined.

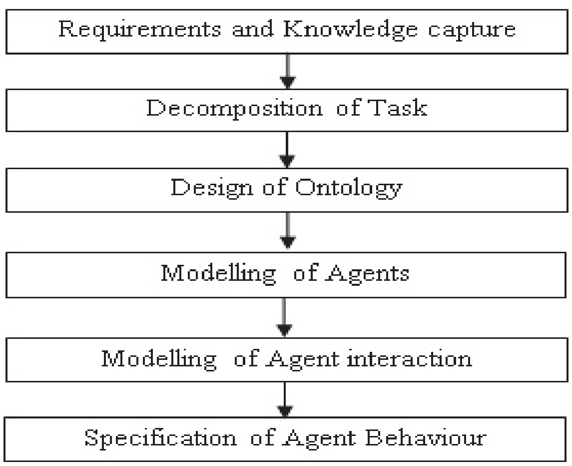

Fig. 2. Design Stages of MAS

C. Agent platform

The Agent Management System (AMS) is the agent who exerts supervisory control over access to and use of the Agent Platform. The agent management system provides white-page and life-cycle service, maintaining a directory of agent identifiers (AID) and agent state. Each agent must register with an AMS in order to get a valid AID and the default yellow page is provided by an agent called directory facilitator (DF).The software component controlling all the exchange of messages within the platform, including messages to/from remote platforms called massage transport system. The standard model of agent platform is shown in Figure 3.

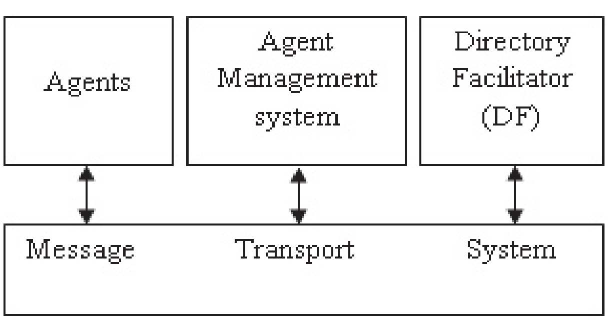

Fig. 3. Agent Platform

D. Proposed Multi Agent System

JADE software [14] is used here for implementation of MAS (Multi Agent System). JADE is a middleware that exchange data between Simulink and java agents. JADE assists the development of multi-agent systems in abidance with FIFA (Foundation for Intelligent Physical Agent) [15]. JADE provides a collaborative environment to design multi-agent system .Agents may be created on different platform i.e. computers, but they have to register on a single central agent AMS (Agent Management System), which keep track of all address. Similarly all agents register their services to single central DF (directory facilitator). DF maps service descriptions to agent identifiers and allow an agent to add/modify/delete information for them.

Figure 4 shows the schematics diagram for implementation of SFCL with Multi Agent System. As Multi Agent System starts all agents register at AMS (Agent Management System) and DF agent. All agents share partial information about circuit with agent coordinator. Agent Coordinator combines this shared information and accordingly detects the fault and sends control signal to circuit breaker.

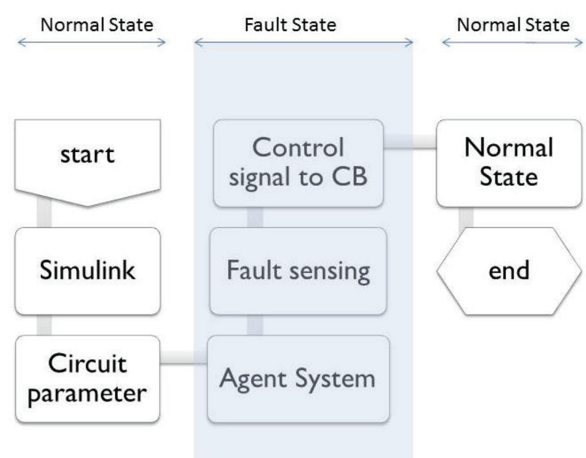

Fig. 4. Schematic diagram of SFCL with MAS.

In JADE, the FIFA-ACL defines library for communication. Every message has performative associated with it that defines the message communication act. We have used ”Inform” type of messages in which sender informs the receiver that given proposition is true. On the basis of intension we have divide our messaging system in four categories.

- *Messages from Agent Coordinator:* In centralized system agent coordinator takes partial plans of each coordinator and then merges their information to take decision about signal that is to be sent to control box.
- *Messages by Agents:* Theses messages are generated by all registered agents at AMS agent. Once, all agents get their relative information, they send back their decision to agent coordinator. These agents deliver their changes to other relevant agents with same registered service at DF as well.
- *Data Amend message:* This message is aired by agents once they finish getting further information from Simulink.
- *Shutting Down:* This message is send by agent coordinator to agents once requirement of agent is finished. After getting this message agent deregisters themselves

form JADE DF (directory facilitator). This deregistration needs to be done manually otherwise a copy of agents services would remain in directory facilitator.

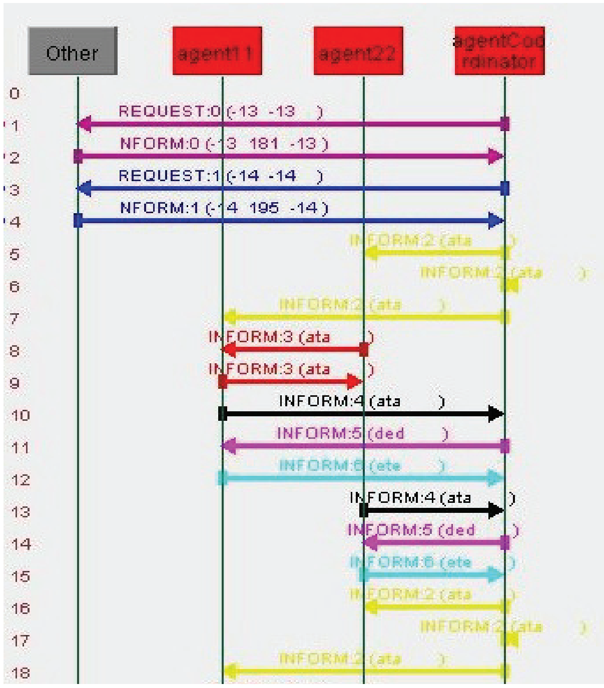

Fig. 5. Sniffer agent diagram of MAS

On the basis of agent behavior we can classify agents in two categories. One is central agent which takes cumulative action by summing up effect of each agent and other is peripheral agents which perform a partial tasks.

Sniffer Agent is used to document conversation between agents as shown in Figure 5. Sniffer Agent is a debugging tool that keep records of message exchange between all agents. Sniffer agent GUI in Figure 4 shows data flow between agents. Firstly Agent Coordinator(Simulink Agent) pass information of circuit to all other agents exists in system. Agent 1 and agent 2 communicate and send circuit information(current) back to agent cordinator which would further pass dicision signal to CB.

III. Simulation Set-up

Matlab/Simulink/SimPowerSystem is selected to design and implement the SFCL model. A complete smart grid power network including generation, transmission and distribution with dispersed energy resources (Wind farm) is also implemented in it. S-function in Matlab is used here to interface JADE. Simulink/ SimPowerSystem have number of advantages over its contemporary simulation software (like EMTP, PSPICE) due to its open architecture, a powerful graphical user interface and versatile analysis and graphics tools [16].

A. Power System Model

Fig.1 shows the power system model designed in Simulink/SimPowerSystem. The power system is composed of a 100 MVA conventional power plant, composed of 3-phase synchronous machine, connected with 200 km long 154 kV distributed-parameters transmission line through a step-up transformer TR1. At the substation (TR2), voltage is stepped down to 22.9 kV from 154 kV. High power industrial load (6 MW) and low power domestic loads (1 MW each) are being supplied by separate distribution branch networks. The dispersed energy resource (Wind Farm) is directly connected with the branch network (B1) through transformer TR3 and is providing power to the domestic loads.

Artificial fault and locations of SFCL (grid integration point) are indicated in the Figure 1. The SFCL is located in such a way that under normal condition the circuit breaker (CB 1) is closed and circuit breaker (CB 2) is open and during fault condition the circuit breaker (CB 1) will open and circuit breaker (CB 2) will close by using proposed multi agent system. Three-phase-to-ground fault point is marked as distribution grid fault. In Figure 1 S-function is controlled by JADE agent and these S-function [17,18] acts as an interface between JADE and Matlab Simulink.

B. Resistive SFCL Model

Critical temperature (Tc), critical magnetic field (Hc) and critical current density (Jc) are the three important factors which defines the superconducting state. These parameters are dependent on each other and material .To maintains super conducting state critical temperature, critical magnetic field as well as critical current density should be below its critical value. When a fault occurs at least one of the three critical parameter immediately reaches to its critical value and superconducting property get vanishes which results sudden increase in resistance (i.e transition from super conducting state to normal conducting state) and because of this increase in resistance, current get reduced. A super conductor operates in super conducting state until a fault current is detected. This property of super conductor used here to develop super conducting fault current limiter.

Figure 6 shows the SFCL model developed in Simulink Sim power system .The parameters and selected values of SFCL are 1) Minimum impedance=.01) Maximum impedance=20 and its working voltage is 12.9 KV. The SFCL works as follows. If passing current is larger than the triggering current level, the SFCL resistance increases its maximum value. When the current level falls below the triggering current level the system goes into normal state. Triggering current is the current flowing through the SFCL before occurring fault.

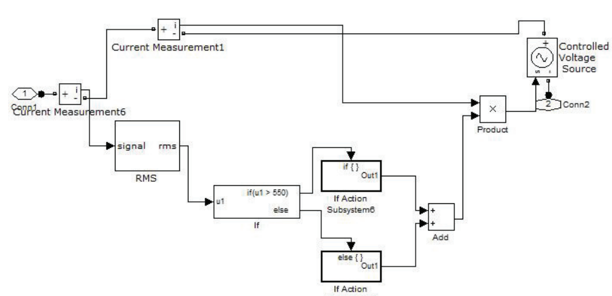

Fig. 6. Single phase SFCL model developed in Simulink/Sim Power system.

IV. Result and Discussion

The performance of multi agent based SFCL is analyzed for three phase line to ground fault at distribution grid as in shown in Figure 1.Three phase fault has been simulated for a period of 0.26 seconds to 0.30 seconds that is fault occurred at 0.26 second and it cleared at 0.30 second.Figure7 and 8 shows the fault current from the wind farm (measured at output of TR3 in Figure 1) without and with the implementation of multi agent based SFCL respectively in case of fault in distribution grid. In Figure 7 without the implementation of multi-agent system the fault current increases to 1922A and with the successful implementation of MAS it is observed that there is a complete reduction in fault current. Under normal condition circuit breaker CB 1 is closed and normal current flows through the entire power network. When a fault occurs in power system the fault current always flows towards fault point i.e. fault current start flowing from wind farm to the fault occurring point and damage the equipment connected to the system. But here the agent 1 of proposed multi agent system always monitors the system whether the fault is occurring or not by sensing the current in the power network. If the agent 1 of proposed multi agent system senses a fault it passes information to the agent 2, then agent 2 passes information to the all other agents of its own kind i.e. between all power houses. The purpose of agent 2 is decision making and sending control signals back to agent 1 that is representing Simulink to reduce the fault current. During fault agent 2 send a control signal '0'to the CB 1 and control signal '1'to CB 2.By getting the respective control signals to the circuit breakers, the CB 1 become open and CB2 is closed and hence SFCL come in to the picture. Now the entire fault current is flowing through the SFCL so the successful reduction in fault current is observed in Figure 8.

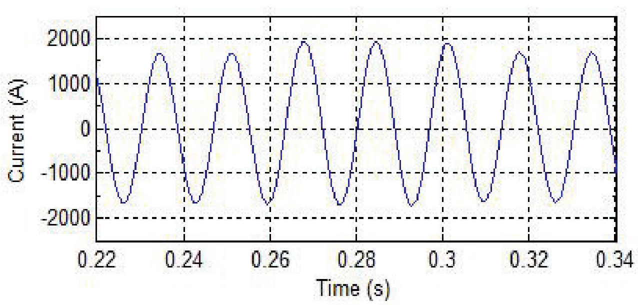

Fig. 7. Fault current from wind farm without SFCL in case of fault in Distribution Grid.

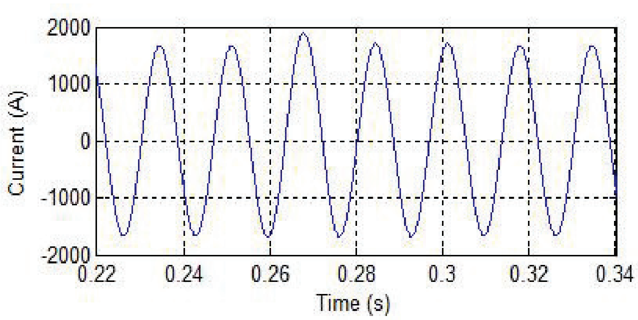

Fig. 8. Fault current from wind farm with SFCL in case of fault in Distribution Grid.

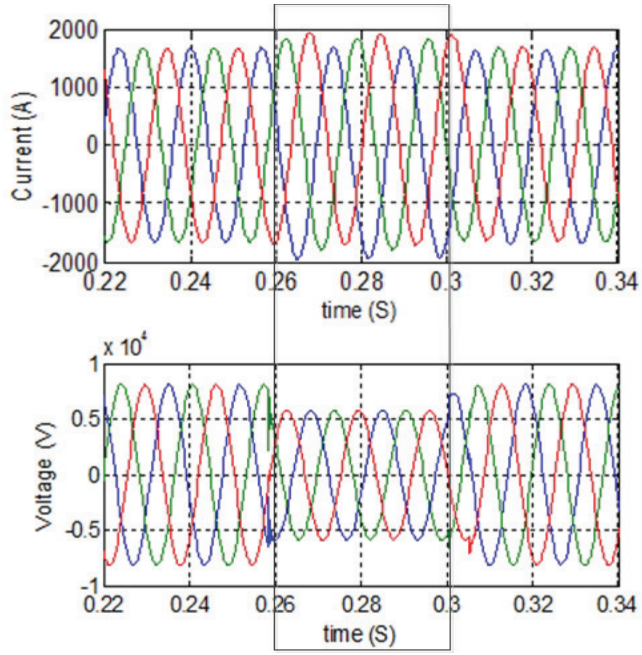

Fig. 9. Three phase Fault current and voltage from wind farm without SFCL in case of fault in Distribution Grid.

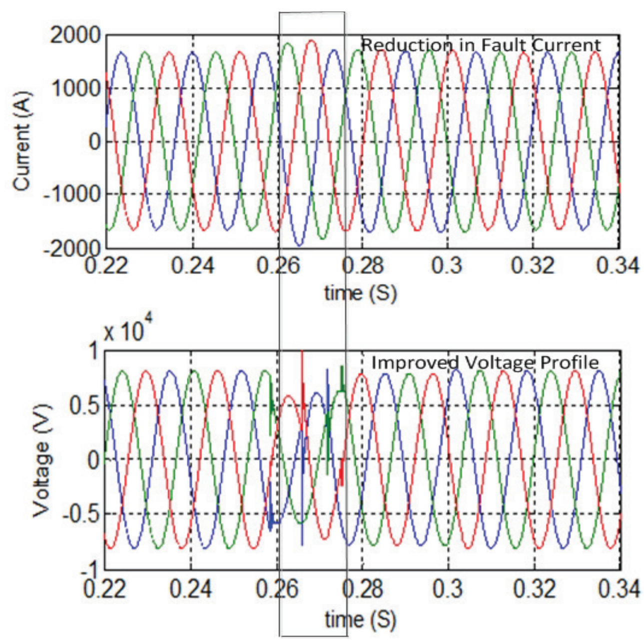

Fig. 10. Three phase Fault current and voltage from wind farm with SFCL in case of fault in Distribution Grid.

TABLE I
EFFECT OF MAS BASED SFCL

	Without SFCL	With SFCL
Current (A)	1980	1875
Voltage (KV)	5.8	7.4
No of Cycles to compensate	3	1

Figure9 and 10 shows the three phase current and voltage from the wind farm (measured at output of TR3 in Figure (1) without and with the implementation of multi agent based SFCL respectively in case of fault in distribution grid From Figure9 and 10 it is observed that there is a successful improve ment of voltage profile and fault current reduction as marked in figure10 with the effect of multi agent based SFCL.The SFCLs essentially use the properties of the superconducting material affected in the presence of an excessive current by having an increase in resistance, thus limitation of the current beyond the predetermined value can be achieved in figure10. The advantage of SFCLs with multi agent system such as automatic over current sensing, automatic recovering and faster over current-limiting operations is expected to be the unique countermeasure to solve the drawbacks. These drawbacks could not be overcome by the conventionally developed FCL . Furthermore, SFCLs with proposed multi agent system can be used to recover some restriction such as voltage sag and stability improvement of the system as in Table 1.These results show that the SFCL can reduce the Volt-Ampere rating by limiting the excessive current in the event of a fault and improve the transient stability of the system.

V. Conclusion

Self-healing is the important attributes of emerging smart grids. In this paper, Multi Agent framework has been discussed with super conducting fault current limiter to facilitate self-healing for a power system that incorporates microgrid. A discussion regarding recent self-healing approaches has been made. Agent protocols have been developed and a microgrid Multi Agent System simulation that demonstrates performance during a casualty requiring self-healing has been implimented. The power system self-healing is difficult, but the case is made for combining multi-agent control with Super conducting Fault Current limiter and micro grids to this end. Three phase ground faults at distribution grid were performed with SFCL installed at grid integration point with the help of proposed multi agent system and successful reduction in fault current and improvement of voltage profile is observed.

References

[1] Litos Strategic Communication,*"The Smart Gird: An Introduction"*,Available:http://www.oe.energy.gov/ Smart Grid Intro-duction.htm, Prepared for U.S. Department of Energy,2012.

[2] M. Amin and B.F. Wollenberg *"Toward a smart grid: power delivery for the 21st century"*, IEEE Power and Energy Magazine, Vol. 3, No. 5,pp.34-41,2005.

[3] K. Moslehi and R. Kumar*"Vision for a self-healing power grid"*, ABB Review,No. 4,2006.

[4] S. Sugimoto, J. Kida, H. Arita, C. Fakui, and T. Yamagiwa *"Principle and characteristics of a fault current limiter with series compensation"*, IEEE Trans. Power Delivery, vol. 11, no. 2, pp. 842847, Apr. 1996.

[5] T. Jamasb, W. J. Nuttall, and M. G. Pollitt *"Future Electricity Technologies and Systems"*, Cambridge: Cambridge Univ. Press, 2006, pp.8397, 235246.

[6] Lin Ye and Liang Zhen Lin *"Study of Superconducting Fault Current Limiters for System Integration of Wind Farms"*, IEEE Trans. applied superconductivity, vol. 20, no. 3, June 2010.

[7] J. Driesen, P. Vermeyen, and R. Belmans*"Protection issues in micro-grids with multiple distributed generation units"*, in Power Conversion Conf., Nagoya, April 2007, pp. 646653.

[8] W.Friedl,L.Fickert,E. Schmautzer,and C.Obkircher*"Safety and reliability for smart-,micro-,and islanded grids"*, presented at the CIRED Seminar: Smart Grids for Distribution, Jun. 2008, Paper 10.

[9] Fabio Bellifemine, Giovanni Caire, Dominic greenwood*"Multi-agent system with JADE"*, John wiley and Son, Ltd, 2004.

[10] M. Pipattanasomporn, H. Feroze and S. Rahman*"Multi-agent systems in a distributed smart grid:Design and implementation"*, in Power Systems Conference and Exposition, IEEE/PES ,2009, pp. 1 -8.

[11] F. M. T. Brazier, B. M. Dunin-Keplicz, N. R. Jennings, and J. Treur*"DESIRE: Modelling multi-agent systems in a compositional formal framework"*, International Journal of Cooperative Information Systems, vol.6, no.1, pp.67-94, 1997.

[12] C. A. Inglesia, M. Garijo, J. C. Gonzalez, and J. R. Velasco*"Analysis and design of multi-agent systems using MAS-CommonKADS"*, in Intelligent Agents IV: Agent Theories, Architectures and Languages, pp.313-326, 1998.

[13] N. W. A. Lidula and A. D. Rajapakse*"Microgrids research: A review of experimental microgrids and test systems"*, Renewable and Sustainable Energy Reviews, vol. 15, no. 1, pp. 186-202, Jan. 2011.

[14] *http://jade.tilab.com/*, accessed January 2013.

[15] Giovanni Caire*"JADE Programming for Beginners"*, TILab S.p.A, 2003, http://jade.cselt.it/.

[16] L. Dessaint, K. Al-Haddad, H. Le-Huy, G. Sybille, and P. Brunelle *"A power system tool based on Simulink"*, IEEE Trans. Industrial Electron., vol. 46, no. 6, pp. 12521254, Dec. 1999.

[17] P.Mendham and T. Clark *" MACSim: A Simulink Enabled Environment for Multi Agent System Simulation"*, 16th IFAC World Congress, Prague, July, 2005.

[18] Charles R. Robinson, Peter Mendham, and Tim Clarke*"MACSimJX: A Tool for Enabling Agent Modeling with Simulink Using JADE"*, journal of physical agents, vol.4, no 3, September 2010.