Wind Turbine Transient Stability Improvement in Power System using PWM Technique and Fuzzy Controller

S.Radha Krishna Reddy, JBV Subrahmanyam, A. Srinivasula Reddy

***Abstract:** In recent years, the increasing concerns to the environmental issues and the limited availability of conventional fossil fuels lead to rapid research and development for more sustainable and alternative electrical sources. Wind energy, as one of the most prominent renewable energy sources, is gaining increasing significance throughout the world. Distributed Generation (DG), based on renewable energy has become a development trend for electric power industry in 21st century. The currently worldwide installed capacity of grid connected wind generators grows rapidly. Therefore detailed analysis needs about the impact of wind power on system security and system operation. But DG is affected by natural conditions being not able to output power continuously and steadily. So when large scale wind turbine generators are incorporated into the grid, they will bring impact on electric power system stability.*

In order to ensure stable operation of electric power system, application of a super capacitor energy storage system (SCESS) superior to other energy storage technologies and Doubly Fed Induction wind Generator (DFIG) are presented in this paper. CESS is connected to the grid at the Point of Common Coupling (PCC). Matlab/Simulink software is used for modelling and simulation analysis. In this paper, transient stability problem if focussed. The simulation results obtained indicate that SCESS can improve transient stability of wind turbine generator system connected to the grid, and by using doubly fed induction generators, electric power system stability can be improved.

***Keywords:** Distributed Generation (DG); Super Capacitor Energy Storage System (SCESS); Transient Stability; Doubly Fed Induction Wind Generator (DFIWG); Fuzzy Controller and PWM Technique.*

I. INTRODUCTION

Distributed Generation technology because of its inexpensive efficiency and environmental protection is attracting more and more attention. Many domestic and foreign experts in this field have had an extensive and in-depth study; they agree that DG penetrated into existing distribution system will be the future development trend. But DG affected by natural conditions cannot output power continuously and steadily, so when large scale wind turbine generators incorporated into the grid will bring impact on the whole electric power system stability, especially when system is at fault conditions.

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The vast majority of presently installed wind turbines are based on the following three main types of electro mechanical conversion systems. The 1st type is normally referred to as a constant-speed or fixed-speed turbine. The 2nd type uses a DFIG instead of a SCIG as variable-speed wind turbine. The 3rd type is called a direct-drive synchronous generator.

The fixed-speed Wind turbines equipped with an induction generator (squirrel cage or wound rotor) have ever been widely used because of the advantage of being simple, robust, reliable and well-proven. Also the cost of its electrical parts is low. However, the disadvantages of uncontrollable reactive power consumption, mechanical stress and limited power quality control lead to little contributions on improving system dynamic behaviour. Especially, owing to its fixed speed operation, all fluctuations in the wind speed are further transmitted as fluctuations in the mechanical torque and then as fluctuations in the electrical power on the grid. With rapid development in power electronic converters recently, an alternative, the variable-speed wind turbine has become the dominant type among the new installed wind turbines. It should be pointed out that the Doubly-fed Induction Generator (DFIG) equipped wind turbine is currently the most popular one due to its capability of controlling reactive power, high energy efficiency, and the fact that the converter rating of appropriately20%-30% of the total machine power is needed.

It is known that the electrical characteristics of DFIG determined by the converter are quite different from the conventional synchronous generators. Power system engineers will have to confront a series of challenges imposed by integration of large wind power with the existing power systems. The impacts of large scale wind power integration on the grid are system scheduling, transmission loading capacity, voltage stability, short circuit capacity, transient stability and frequency stability. One of important issues is the impact of wind power penetration on the dynamic behaviour, e.g. the transient stability,[1]of an existing interconnected large-scale power system.

The main aspects having a possible impact on transient stability issues are:

1. Wind resources are usually at different locations than conventional power stations. Hence, power flows are considerable different in the presence of a high amount of wind power and power systems are typically not optimized for wind power transport. This aspect can be more or less severe in different countries.
2. Wind generators are usually based on different generator technologies than conventional synchronous generators.

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3. Wind generators are usually connected to lower voltage levels than conventional power stations. Most wind farms are connected to sub-transmission (e.g.110 kV, 66 kV) or even to distribution levels (e.g.20 kV, 10 kV) and not directly to transmission levels (>110 kV) via big step-up transformers as in case of conventional power stations.
4. Other aspects, especially the fluctuating nature of wind power have not been relevant to transient stability problems because wind speed variations are too slow compared to the time frame relevant to transient stability (one to ten seconds). However, because of limited predictability of wind speed, systems with high amount of wind power usually require higher spinning reserve than conventional power systems, which adds inertia to the system that has influence on transient stability. In this sense wind fluctuations are having an indirect influence on transient stability issues.

A large number of wind farms connected to the grid, especially at the end grid, will greatly change the power distribution and transmission lines loading. In addition, the wind turbine itself is different from the traditional synchronous generator with respect to dynamic characteristics; therefore the system transient stability needs to be enhanced.

Existing Techniques for Transient Stability Improvement:

1. Using doubly-fed induction wind generator (DFIWG) can improve transient stability
2. SCESS is proposed for stability analysis,[2] but using wind turbine fixed-speed squirrel-cage generators, so its electrical and mechanical characteristics will slow the recovery of post-fault voltage, it connected to the weak the grid will lead voltage, rotor instability, interaction with the grid so that it bring impact on voltage transient stability.
3. STATCOM control program is proposed,[3] but only can control reactive power.
4. STATCOM/BESS is introduced,[4-6] although it can control both active power and reactive power, but battery energy storage system has slow reaction and short lifetime.

Proposed Technique for Transient Stability Improvement:

Therefore using SCESS and doubly fed induction wind generator (DFIWG) to solve problem on transient stability of multi-machine wind turbine generator system connected to the grid[11] is presented in this paper. On one hand, as fuzzy logic controller can be used to stabilize the system,SCESS uses control program based on fuzzy logic controller. On the other hand, using DFIWG electric power system stability can be improved. Matlab/ Simulink software is used for modelling and simulation analysis, the simulation results indicates that SCESS and doubly fed induction generators can improve transient stability of multi-machine wind turbine generators connected to the grid.

II. DOUBLY-FED INDUCTION WIND GENERATOR (DFIWG)

At present, large and medium sized wind power generation systems mostly use asynchronous generator unit, in order to capture maximum wind energy under various speeds. Variable speed constant frequency (VSCF) wind power generators become a main choice of large capacity wind generation equipment.[7] When wind turbine runs with variable speed, the generator connected to it should be with variable speed operation, outputting constant voltage and constant frequency power to the grid. Wound rotor doubly-fed induction generator, combined with the latest IGBT inverter technology and PWM controller; the VSCF wind power generation system can be realized.[3] The AC excitation VSCF wind turbine using doubly fed induction generator connected to the grid is the optimal one of all programs. DFIWG is on the basis of ordinary wound induction generator in addition a converter connected in between the rotor slip ring, the stator and its control system. The generator output power supplied to the grid is composed of two parts: i.e. the output power from the stator directly and the output power from the rotor through inverter. DIFWG stator is connected to the grid; the rotor is excited through a converter supplying three phases slip frequency current, as shown in-Fig.1[3]

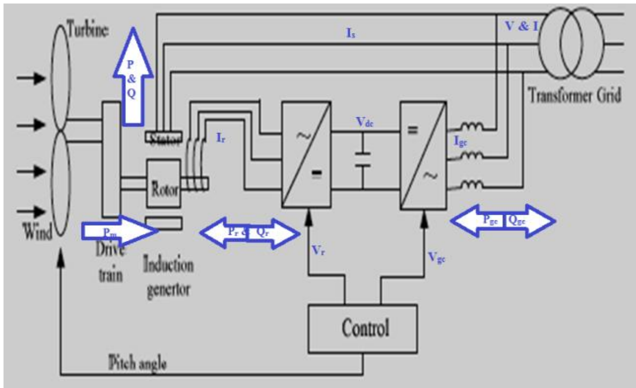

Fig.1 Variable speed wind turbine DFIG connected to the grid

When the wind speed slowed, the generator speed is less than synchronous speed of stator rotating magnetic field, the generator is in sub-synchronous operation, at this time the converter provides AC excitation to the generator rotor, the stator sends electric energy to the grid; when the wind speed increased, the generator speed is greater than synchronous speed, the generator is in super- synchronous operation, at this time the generator stator and rotor send electric energy to the grid at the same time, the energy of converter reversely flows; when the generator speed is equal to synchronous speed, the generator is in synchronous operation, at this time the generator is running as a synchronous machine, the converter provides DC excitation to the rotor. It can be seen when the generator speed changes, if the rotor current frequency corresponding change is controlled, it will make the stator current frequency remain constant, and is consistent with the grid frequency, so VSCF control can be achieved.

III. SUPER CAPACITOR ENERGY STORAGE SYSTEM(SCESS)

SCESS mainly is composed of super-capacitors and power electronic devices, the energy storage unit is controlled by using power electronics-based voltage source or current source converters, its way connected to the grid can be adjusted cleverly, through controlling converter reasonably can independently regulate active power and reactive power, and at the same time can compensate system harmonics,

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suppress voltage fluctuations and flicker fluctuations. Therefore super capacitor can smoothen wind turbine output power, regulate output voltage. Using super capacitor components array in SCESS to store energy in the form of electric field energy, when energy is emergency absence or necessary, it releases its stored energy through controlling system, so as to compensate accurately and quickly active power and reactive power as required by system, achieve the balance of energy and stability control. In this paper, the control method of SCESS is making use of DC/DC converter based on the sinusoidal Pulse-Width Modulation voltage source converter and fuzzy control.

A. Super Capacitor Modelling

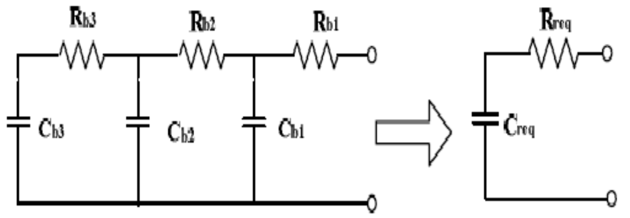


Fig.2 Super capacitor constant equivalent circuit

Super capacitor also known as electric double layer capacitor is a new energy device between electrostatic capacitor and battery, it has an excellent pulse charge-discharge performance and large capacity storage performance, as current domestic capacity of super capacitor monomer has been ten thousand Farah level. Super capacitor can be recharged to rated value in a short time and can provide relatively large energy. When main electric power source failure or system voltage low caused by poor contact, super capacitor can act as the back-up and supplementary. The equivalent circuit of super capacitor-cell is shown in Fig.2.

B. Bi-directional DC-DC Buck/Boost Converter Modelling

Fig.3 shows the bi-directional dc/dc converter used in SCESS. Super capacitor energy storage device mainly works in three states: when Bi-directional DC-DC Buck / Boost Converter charges super capacitor, it is BUCK energy storage state; in order to maintain a constant voltage of the DC link, super capacitor provides energy to the DC link bus, which is equivalent to forward BOOST running, in some cases, when needed to absorb electric energy at the DC link side, then maintain a constant voltage of the DC link side, current direction is reversed. Circuit of the DC link side is looked as load side, which is equivalent to reverse BOOST running. i.e. energy storage device through the DC-DC Buck /Boost Converter charging and discharging provides constant voltage support for the DC bus, it is constant voltage operation; when energy storage device does not work, there is no energy flow, capacitor terminal voltage is constant, is the standby state. Super capacitor energy storage device runs continuously and circularly in these three states.

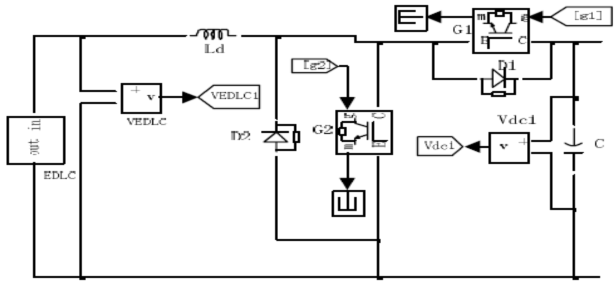


Fig.3 DC-DC Buck / Boost Converter

C. PWM Voltage Source Converter Modelling

The inverter of SCESS adopts PWM three-phase voltage source converter, the structure of the inverter circuit is shown in Fig.4.

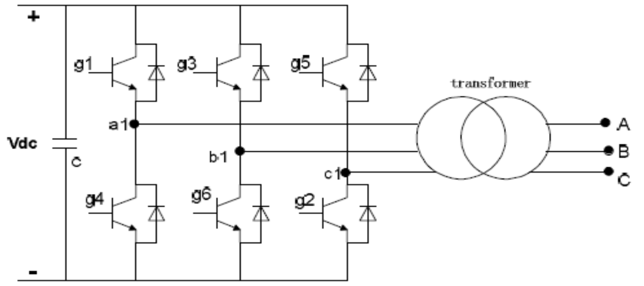
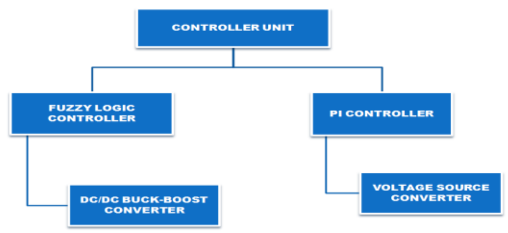


Fig.4 PWM VSC converter

The inverter bridge arm switch is composed of insulated gate bipolar transistors (IGBT) and anti- parallel fast recovery diode. The VSC converts the DC voltage across the storage device into a set of three-phase AC output voltages. These voltages are supplied to the AC system through the impedance of the coupling transformer.[2] Three-phase AC output voltage waveforms of the inverter depend on driving signal waveforms of the inverter bridge arm switch; i.e. the PWM modulation mode[8]. The PWM voltage source converter (VSC) provides a power electronic interface between AC power system and super capacitor, DC link voltage Vdc .The grid point voltage is maintained constant by the VSC.[9]

D The control system of SCESS



SCESS Control block

1) *DC-DC buck/boost converter control*

The control system diagram of DC-DC buck/boost converter is shown in Fig.5. When wind farm power is less than the reference power, energy from the super-capacitors and series inductance is supplied to electrical source at the DC link side, super capacitor discharge to compensate for the lack of system power. At this time IGBT1 disconnect, IGBT2 and D1 act as boost step-up converter. When power at point of wind farm connected to the grid)is greater than the reference power,

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energy from electrical source at the DC link side is supplied to super capacitor, energy is stored, at this time IGBT2 disconnect, IGBT1 and D2 act as buck step-down converter. Therefore by controlling complementary conduction of g1 and g2 make g1 or g2 switch tube current zero crossing, at this time the other switch tube works. Thereby enables bi-directional DC-DC buck/boost converter to work alternately.[10]

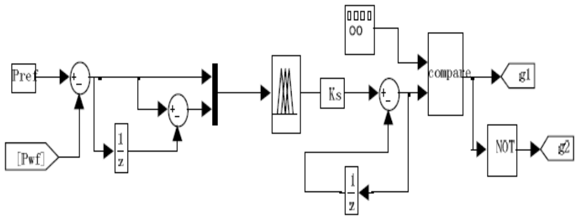

Fig.5 Fuzzy logic control of DC-DC converter

The control objective of fuzzy logic controller based on power regulation is to track wind speed changes, and draw maximum power from wind energy.It requires two real-time measured values: power deviation E=Pwf-Pref and power deviation rate Ec=d(Pwf -Pref)/dt. The fuzzy logic controller has a dual-input single-output structure in this paper, error E and error rate Ec can more stringently respond to the Dynamic characteristics of output variables in the control process.

Two-dimensional fuzzy logic controller has two input linguistic variables: power deviation E and power deviation rate Ec, and an output linguistic variable: power corrected value. Their fuzzy sets are defined as (NB, NS, ZO, PS,PB),the meaning of linguistic variables fuzzy sets respectively is NB (negative big); NS (negative small); ZO (zero); PS(positive small); PB(positive big).[10-11]

The error signal between the power at the point of wind farm connected to the grid and the reference power is progressed through a fuzzy logic controller and produces the dc–dc buck/boost converter duty cycle. Then the duty cycle is compared with the saw tooth carrier wave to generate the gate signals for buck/boost converter as shown in Fig.5.

2) PWM VSC control

The control system of the PWM VSC is shown in Fig.6.The PI controllers determine reference d- and q-axis currents by using the difference between the DC link voltage Vdc and reference value Vdc*, and the difference between terminal voltage Vk and reference value Vk* respectively. The reference signal for VSC is determined by converting d- and q-axis voltages, which are determined by the differences between reference d-q axes currents and their detected values.

Parameters of the PI controllers are determined by trial and error method. The PWM signal is generated for IGBT switching by comparing reference signals, which is converted to 3-phase sinusoidal wave with the triangular carrier signal. High switching frequencies can be used to improve the efficiency of the converter, without incurring significant switching losses. In the simulation analyses, the frequency of the triangular carrier signal is 1000 Hz. The DC voltage across the capacitor Vdc is kept constant through the 6-pulse PWM converter. The VSC rating is considered to be the same of wind farm rating.[2,9]

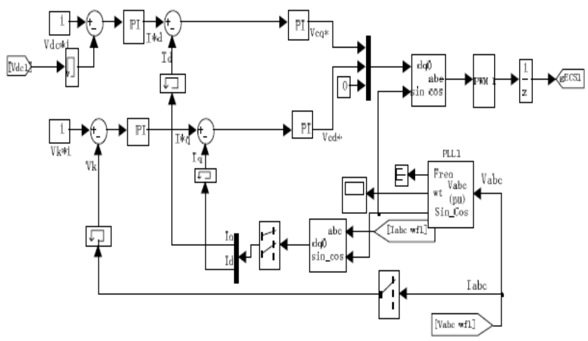

Fig.6 PWM VSC control

IV. SYSTEM SIMULATION

The system simulation model of multi-machine wind turbine generators connected to the grid is composed of the infinite power source, steam turbine synchronous generator, hydraulic turbine synchronous generator, multi-machine wind induction generators, 115kV ring network, as shown in Fig.7. In this paper, ordinary multi-machine wind turbine induction generator system connected to the grid and multi-machine doubly-fed wind turbine induction generator system connected to the grid respectively were modelled, the latter (program 2) based on the former(program1) increases SCESS, and using double-fed wind turbine induction generators substitute for ordinary wind turbine induction generators.

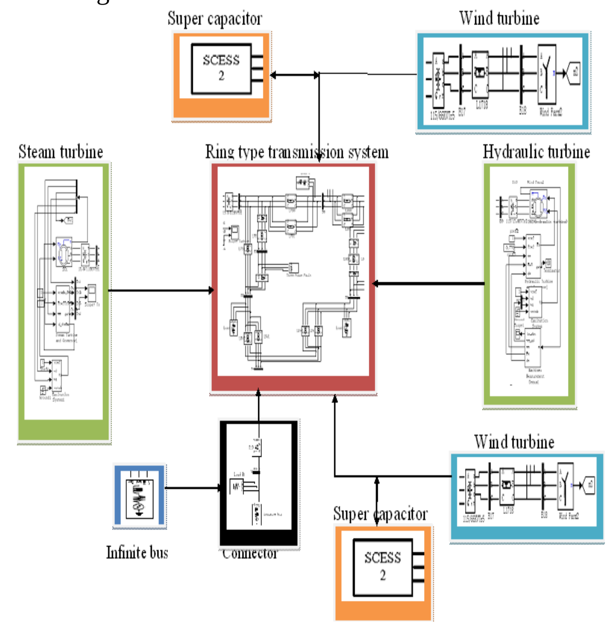

Fig.7 Modelled System

SCESS is connected at public connection point between wind farm and the grid. The two wind farms composed of multi-machine double-fed induction wind power generator system respectively is connected at the public connection point, their power is transmitted by the transmission lines, after step-up, they are connected to main system 115kV ring network. This model is mainly used for power system transient simulation. Two wind farms are composed of 10 wind turbines generating units, each 10MW wind turbine is constituted of turbine, accelerator, doubly-fed induction generator,0.575/66kV transformers and parallel capacitors for reactive power compensation.

The DC/DC converter is based on fuzzy logic control, voltage source inverter is based on the pulse width modulation control in SCESS. System base capacity is 100MVA, frequency is 60HZ.

V. SIMULATION RESULTS ANALYSIS

In this paper, Matlab/ simulink software is used for modelling and simulation analysis of multi-machine wind turbine generators system connected to the grid, simulation results of program 1 and program 2 are as follows.

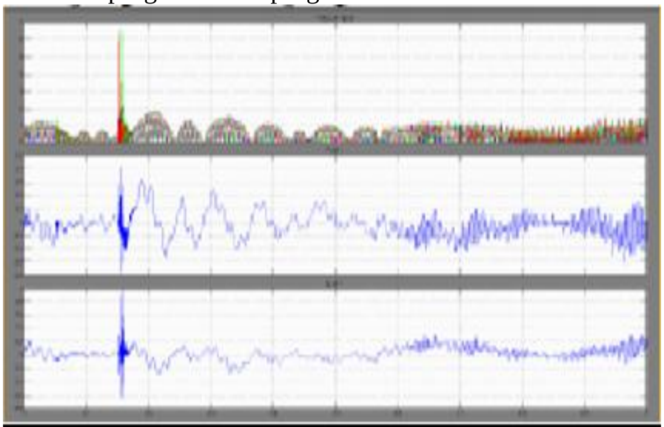

Fig.8 Terminal voltage, active power and reactive power of wind farm 1 in program 1

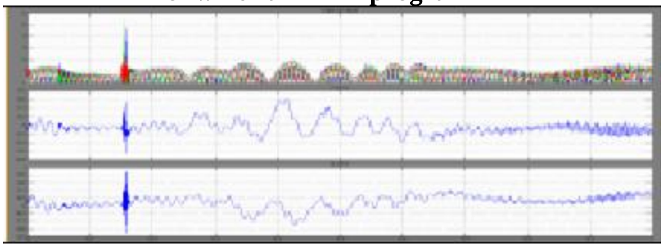

Fig.9 Terminal voltage, active power and reactive power of wind farm 2 in program 1

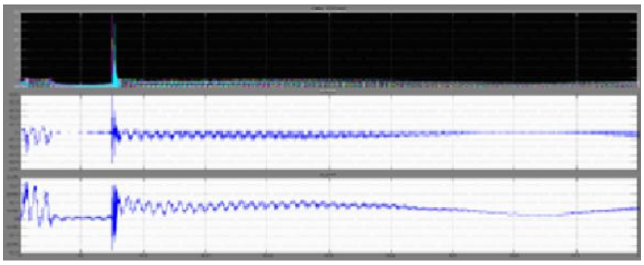

Fig.10 Terminal voltage, active power and reactive power of wind farm 1 in program2 with SCESS

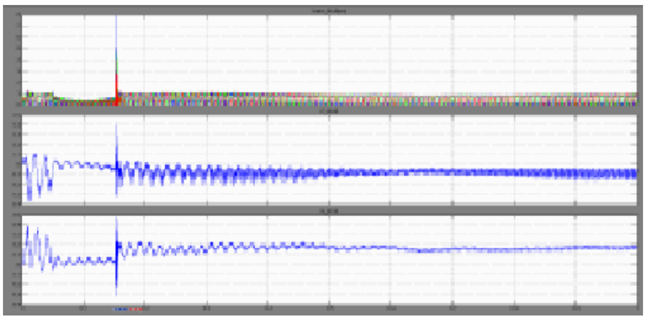

Fig.11 Terminal voltage, active power and reactive power of wind farm 2 in program2 with SCESS

Assumed that when t = 0.05~0.15s,on line L751 occurs three-phase ground fault, through switching off switch g2 of the DC-DC buck/boost converter in program 2, SCESS absorbs transient energy, thus can control active power. Reactive power of wind farm is supplied on the basis of the error signal between terminal voltage of wind farm and reference voltage.

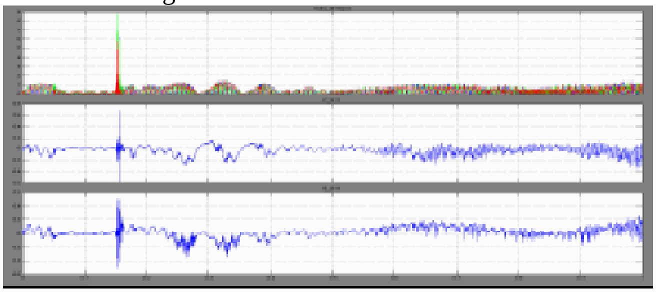

Fig.12 Terminal voltage, active power and reactive power of wind farm 1 in program 2 without SCESS

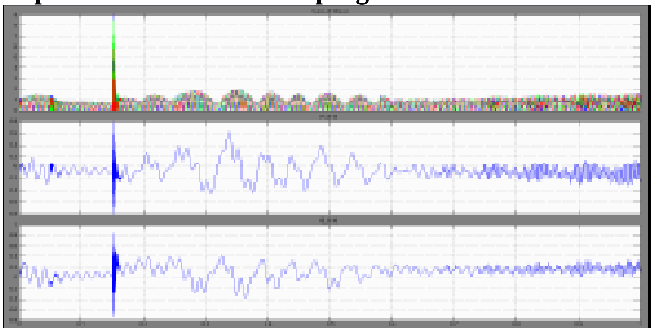

Fig.13 Terminal voltage, active power and reactive power in wind farm 2 in program 2 without SCESS

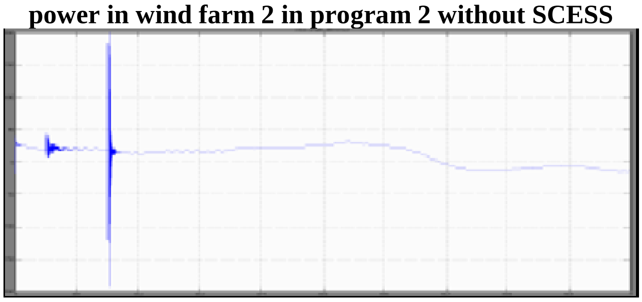

Fig.14 Rotor angle difference of synchronous generators in program 1 without SCESS

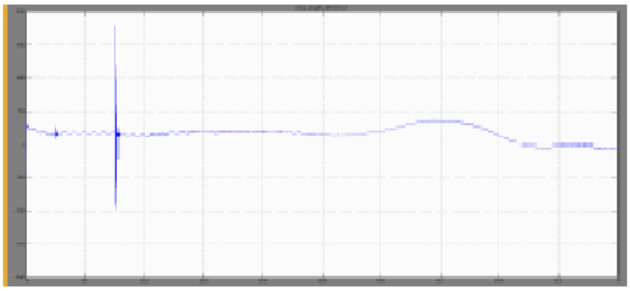

Fig.15 Rotor angle difference of synchronous generators in program 1 with SCESS

In program 1 and program 2, when on line L751 occurs three-phase short circuit, the terminal voltages, active power and reactive power respectively of wind farm 1 and 2 are shown in Fig.8,9,10,11. Fig.8,9 shows the system connected to the grid with common wind turbine induction generator and without SCESS control,Fig.10,11show the system connected to the grid both with doubly-fed wind turbine induction generators and with SCESS control. But Fig.12, 13 show the system connected to the grid only with doubly-fed wind turbine induction generators and without SCESS control.

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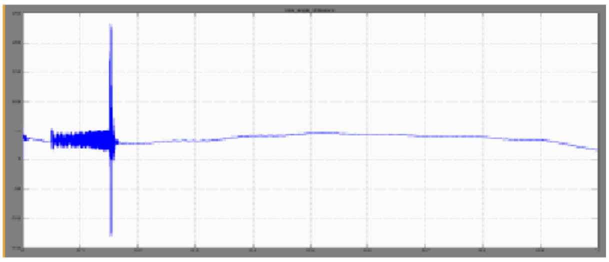

Fig.16 Rotor angle difference of synchronous generators in program 2 without SCESS

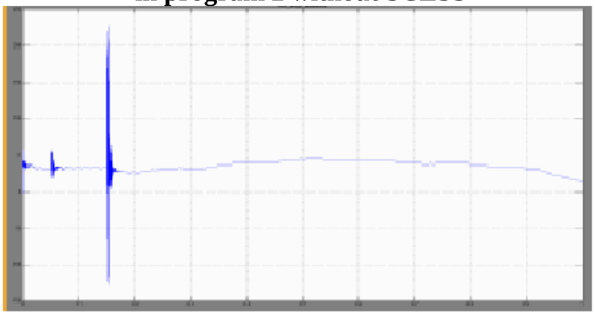

Fig.17 Rotor angle difference of synchronous generators in program 2 with SCESS

Fig.14, 15, 16, 17 respectively show load angle response of synchronous generators in program 1 and program 2.

By comparing and analyzing the simulations, it is observed that the doubly-fed wind turbine induction generator can participate in the regulation of reactive power, improve system stability, after a three-phase short-circuit fault.It is able to withstand short-term voltage drop rather than out of operation, it can increase output of system reactive power, providing some help for recovery of system voltage.

It is clear from these simulation figures that SCESS can charge and discharge properly to smoothen the output power to the grid. So SCESS can maintain bus voltage constant. It also shows that SCESS and doubly-fed wind turbine induction generator in program 2 can have evident effect in damping load angle oscillation.

VI. CONCLUSION

Fuzzy logic controller is applied in nonlinear systems to stabilize it. Double-fed wind turbine induction generator can regulate reactive power in addition to stabilizing the system,SCESS based on Fuzzy Logic Controller superior to other energy storage technologies for comprehensive performance and Double-Fed Wind turbine Induction Generators substituting for ordinary wind turbine induction generators are proposed.The simulation results indicate that SCESS and doubly fed induction generators can improve transient stability of multi-machine wind turbine generators connected to the grid.

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