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Fast Control Strategy For Stabilizing Fixed Speed Wind Turbines in an Islanded Distributed System

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ABSTRACT: Driven by economic, technical and environmental reasons, the energy sector is moving into an era where electrical demand will be met through wide spread installation of distributed resources or what's known as Distributed Generation Systems. This paper deals with a distributed generation system (DGS) with fixed speed induction generator based wind turbines (FSWTs) which are sensitive and vulnerable to voltage disturbances and reactive power deficiency. Consequently, the control and protection strategies should be prompt and precise to avoid undesired wind generator shut down. In this paper, a distributed generation system with three combined heat and power generators (CHPs) and three fixed speed induction generator based wind turbines (FSWTs) is initially connected to the grid and feeding dynamic load groups. A fast control strategy is proposed to stabilize the system when the distributed generation system (DGS) is islanded from grid after the occurrence of a three phase fault. This includes governor and exciter control of CHPs, reactive power compensation, and load shedding. Simulation is done in PSCAD/EMTDC and results are analyzed.

KEYWORDS: DGS, FSWTs, CHPs, governor control, reactive-power compensation, load shedding.

I.INTRODUCTION

The environmental regulations due to green house gas emissions, the electricity business restructuring , and the recent development in small scale power generation are the main factors driving the energy sector in to a new era, where large portions of increase in electrical energy demand are met through widespread installation of distributed resources or what's known as 'Distributed Generation Systems'. DGS facilitate electric power generation in proximity of load centres. As a result, DGS can give commercial consumers various options in a wider range of high reliability- low price combinations.DGS can operate either in a grid-connected mode or in an islanded mode within a micro-grid. In the islanded mode of operation, a cluster of DG units serviced by a distribution system is formed to maintain the reliability of critical loads, mainly when the utility supply is not available.

The behaviour of power system is mainly determined by the behaviour and interaction of generators connected to it. When the penetration of wind generation increases its effect on power system also increases. This leads to careful study of stability of power system with wind generators. Not only the renewable generation units, but also the increasing utilization of power electronics devices in a DGS has changed the power system characteristics. Some literatures reveal that the recent large scale system blackouts are increasingly because of voltage collapses caused by reactive power deficiency, rather than frequency drops [1]. In addition wind turbines (WTs)' induction generators are more sensitive to voltage than conventional synchronous generators, so an induction generator-based WT is more vulnerable to voltage disturbances.

Conventional system protective schemes, such as under frequency load shedding (UFLS) or under voltage load-shedding (UVLS), may not respond quickly enough after disturbances in the changing power systems [1, 2]. Some adaptive strategies have been proposed in the literatures [3].However, such adaptive strategies may still have some problems, for instance, in [3], a centralized UFLS control system encounters the problems of the control commands transmission delay. Furthermore, such conventional load shedding schemes are not suitable for stabilizing fixed-speed induction-generator (FSIG)-based WTs during disturbances. An ideal DGS should possess the characteristics of compatibility and flexibility, which ensures that the system can operate in either grid connection or standalone.

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Although variable speed doubly-fed induction-generator (DFIG) - based wind turbines are most popular now, many fixed-speed induction-generator-based wind turbines (FSWTs) installed early are still in operation, therefore it is still worth investigating fixed speed induction generator based wind turbines.

This study proposes a fast control and protective strategy, to enable the FSWTs involved DGSs respond in a timely manner and avoid undesired disconnections of WTs, which may be caused by generator over-speed protection.

II.FAST CONTROL STRATEGY FOR AN ISLANDED DGS

The fast control strategy intends to maintain the balance of the generation and the loading in an islanded DGS in a prompt manner. The main generation units are FSWTs and CHPs.

A. Fast Control Strategy

In this study, initially DGS with three CHPs and three FSWTs is connected to the grid as shown in Fig.1. After the occurrence of a fault on the grid side, the DGS is islanded permanently. To stabilize the DGS during islanding, the DG units and loads need to be re-adjusted and re-balanced according to the system status.

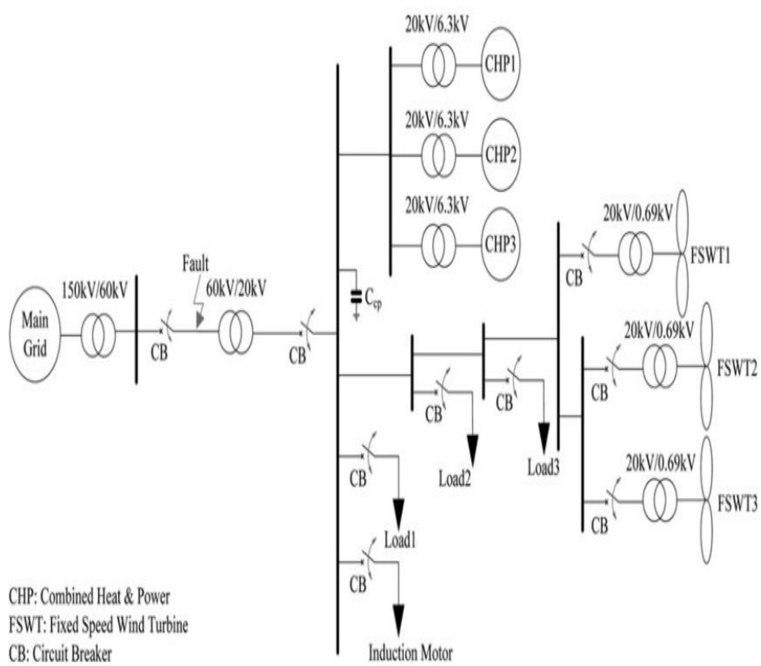

Fig.1 DGS system under study initially connected to grid.

This Fast control strategy mainly consists of two aspects viz. are Generation control and Load shedding. Generation control consists of control of active and reactive power of CHPs and FSWTs. If it is inevitable, we have to go for load shedding. Even this should be based on an optimized priority table. Detailed description of these aspects is given in the following sections.

B. Generation Control

Generation control for an islanded DGS mainly deals with the control of CHPs generation. It contains three key operations:

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i. Control mode shifts:

Since FSWTs have no further active power and reactive power control ability, CHPs are the major control objects in generation control. Once an islanding of a DGS is detected, the CHPs' control mode should shift from Control Mode 1 to Control Mode 2, as indicated in Fig.2

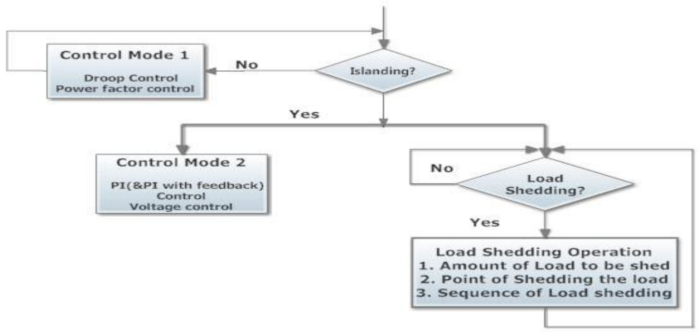

Fig.2.Fast Control Strategy on an Islanded DGS

Control Mode 1 is implemented when the DGS is integrated with the main grid. In Control Mode1, the active power control is Power –frequency droop control; the reactive power control is power factor control.

Control Mode 2 is implemented when the DGS is islanded from the main grid. In Control Mode 2, the active power control is PI (proportional integrator) control, reactive power control is voltage control, but if there is more than one active power controllable generator, only one governor of these generators can utilize PI controller, the others may choose PI with a feedback controller [4].

ii. CHPs' releasing reserved generation:

After DGS islanding, because of the loss of active power and reactive power exchange from the main grid, the DGS reserved generation capacity should be adjusted adaptively and promptly. To keep the voltage and frequency in the required range, the generated active power and the reactive power should be balanced with consumptions. Accordingly, the adjustable generation units are supposed to release reserved generation to satisfy the possible power deficiency in the DGS.

The active power control is implemented by the CHPs' governor control, as depicted in Fig. 3, in which the parameter P_r is the reference power in per unit, K_c is the ambient temperature load limit and their maximum values are both 1.0.

If reserved generation is to be released, P_r and K_c need to increase, even into 1.0 to maximize releasing of generation reservation.

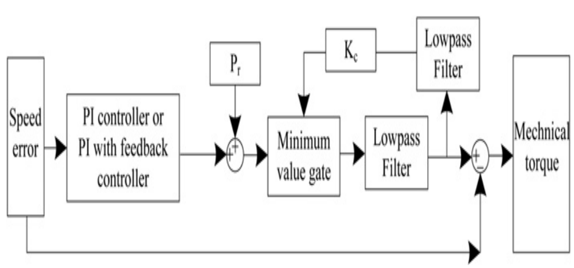

Fig.3. Governor model for CHPs.

Regarding the reactive power control for the CHPs, IEEE Alternator Supplied Rectifier Excitation System #2 (AC2A) [5] as simplified in Fig. 4, is utilized. The voltage regulator reference (V_r) is adjusted from 1.0 under Control Mode 1 to 1.2 under Control Mode 2, in order to release the CHPs' reserved reactive power.

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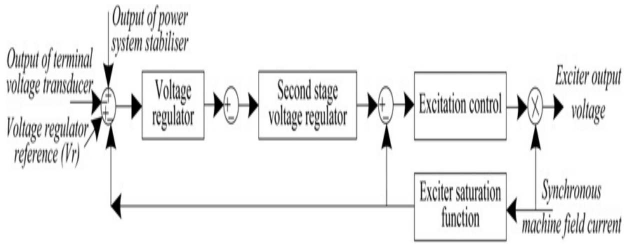

Fig.4. Exciter model for CHPs.

iii. Reactive power compensation:

Although the CHPs' adjusting generation is performed immediately after detection of DGS islanding, the adjusting procedure still takes certain time, that is, several seconds. Assuming there are several FSWTs and a motor in a DGS, they are all induction machine based, and they are all sensitive to reactive power deficiency. During this period of time, the WTs' and the motor's terminal voltage may not be restored sufficiently to stabilize the FSWTs and the motor. Therefore once insufficient voltage is detected, the reactive power compensation operation should be performed, that is, a shunt capacitor C_{cp} should be switched on. The implementation location of the C_{cp} is located at the disconnecting point between the grid and the DGS. The implementation time is decided at the moment when the FSWTs' terminal voltage restores to a peak value, which may be still lower than 1.0 pu. The amount of reactive power compensation, fulfilled by C_{cp}, is decided by the reactive power deficiency, Q_{Def}, of the DGS because of islanding.

C. Load Shedding

If Reserve power capacity P_{res} is less than the power deficiency $P_{def,}$, then the load shedding command must be issued. Total amount of load to be shed P_{LS} is given by

$$P_{LS} \approx P_{def} - P_{res} \quad -(1)$$

If more than one load has to be shed, the priority is decided by customer information from the Load Management System (LMS), for example, the payment of customers, their social importance, their economic characteristics etc. For loads with the same priority, the sequence of load shedding depends on the loads characteristics. Loads with smaller dP/dV, dQ/dV, dP/df, |dQ/df| may be shed earlier, the loads with greater dP/dV , dQ/dV , dP/df, |dQ/df| may be shed later. Such a load shedding sequence should be preset.

III. PSCAD/EMTDC IMPLEMENTATION

To demonstrate the effectiveness of the fast control strategy, PSCAD/EMTDC [6] is used for power system simulation.

FSWT Model:

Three FSWTs are all rated at 600 kW, 0.69 kV. The mechanical torque [7] is formulated as below

$$Tm=1/2\ \rho RAv_{wind}^{2}\ C_q \quad -(2)$$

where ρ is the air density in kg/m^3, R is the wind turbine radius in m, A is the wind turbine rotor area in m^2, v_{wind} is the wind speed in m/s and C_q is the torque coefficient [7].

C_q is obtained by (3)

$$C_q= C_p/ \lambda \quad -(3)$$

where ,C_p is the power coefficient, may be expressed by (4), [8] λ is the tip-speed ratio

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$$C_p=0.34(\frac{125}{\lambda}-6.94)e^{((-\frac{15.5}{\lambda}))} \quad -(4)$$

TABLE 1 FSWT PARAMETERS[9]

Parameter	**Rating**
Power	600KW
Voltage	0.69KV
Wind Turbine Radius	21m
Rotational Speed	30RPM
Gear ratio	1:50.5

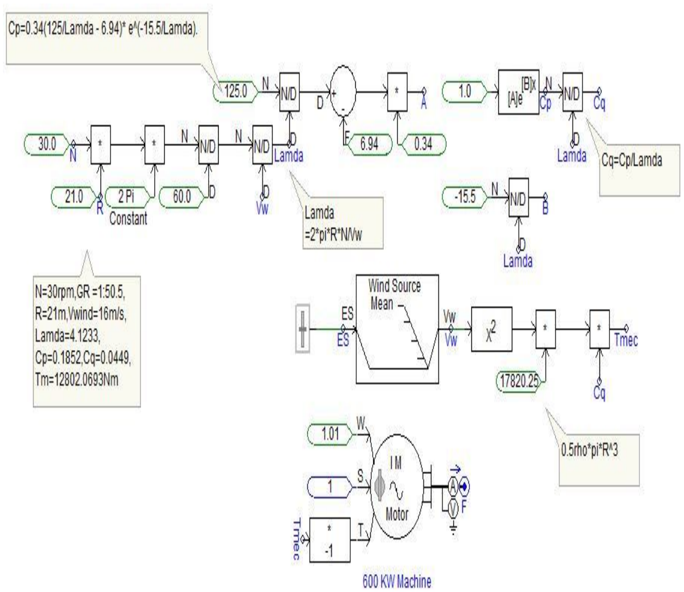

Fig.5. Design of FSWT based induction generator in PSCAD

CHP Model:

Three CHPs are all rated at 3.3 MW, 4.5 MVA, and 20KV.Governor control is done by combination of pf droop in control mode1 and PI control (one CHP) or PI with feedback control (for all other CHPs) in control mode 2.

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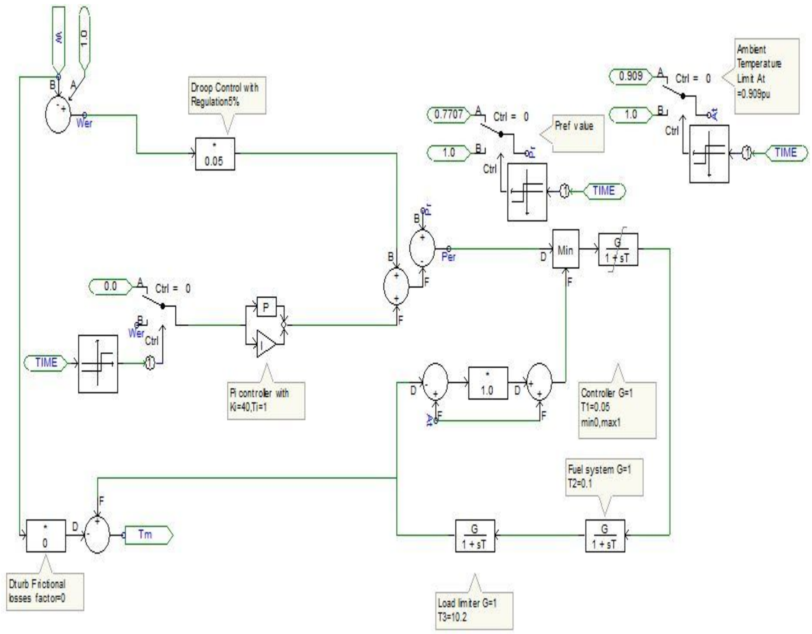

Fig.6. Governor with droop control (control mode1) and PI control (control mode2)

Here, we can see that after islanding along with pf droop control additionally PI control comes into picture. Similarly, for other CHPs we can see the PI with feedback in Fig7.

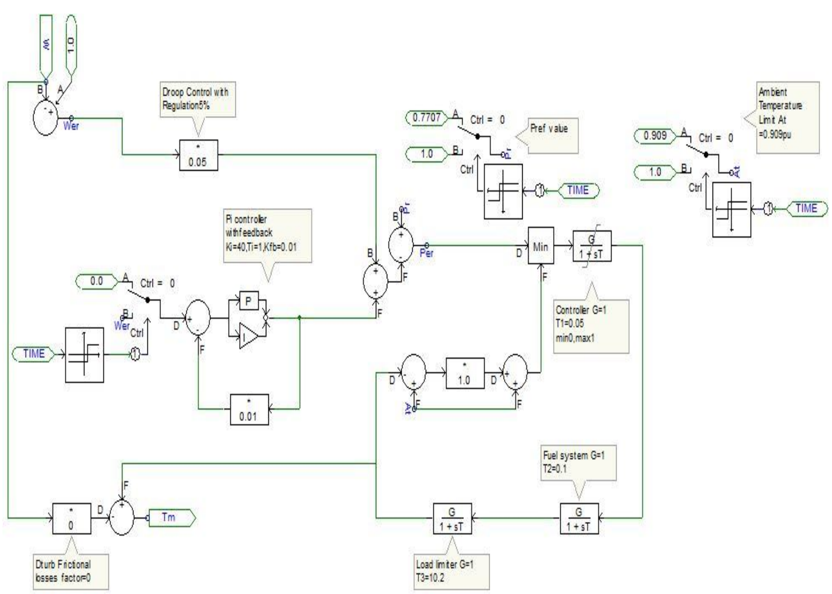

Fig.7. Governor with droop control (control mode1) and PI with feedback control (control mode2)

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For Exciter, we are using AC2A type model with available Power system stabilizer PSS2B. A CHP generator can be shown in Fig.8.

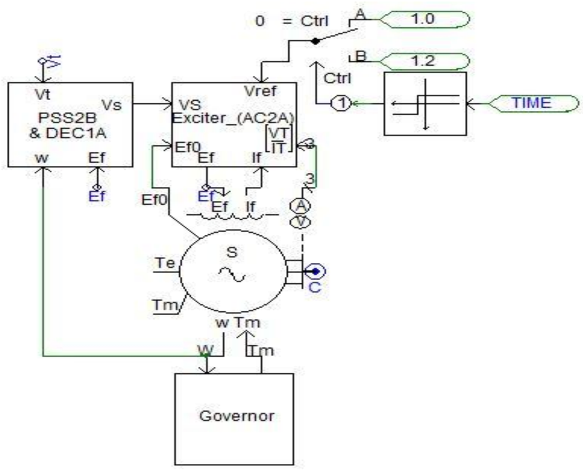

Fig.8. A CHP generator with governor and exciter

Load groups:

TABLE 2. RATED POWERS OF DISTRIBUTED LOAD GROUPS

Load group	**Rated Active power MW**	**Rated Reactive power MVAR**
Load 1	12.1752	3.6528
Load 2	0.3687	0.0681
Load 3	0.3687	0.0681
Motor	0.48	0.08

TABLE 3. CHARACTERISTICS OF LOAD GROUP 1

Load no.	**Rated Active Power MW**	**Rated Reactive Power MVAR**	**dP/dV**	**dQ/dV**	**dP/dF**	**dQ/dF**
1.1	2.0292	0.6088	0.5	2.0	1.5	-1.0
1.2	1.8263	0.5479	1.8	2.0	1.5	-1.0
1.3	1.0146	0.3044	1.0	1.5	1.5	-1.0
1.4	1.9785	0.5936	1.0	5.0	1.5	-1.0
1.5	1.6741	0.5023	1.0	2.0	1.5	-1.0
1.6	1.3697	0.4109	1.0	2.0	1.5	-1.0
1.7	1.2175	0.3653	1.0	2.0	1.5	-1.0
1.8	1.0653	0.3196	1.0	2.0	1.5	-1.0

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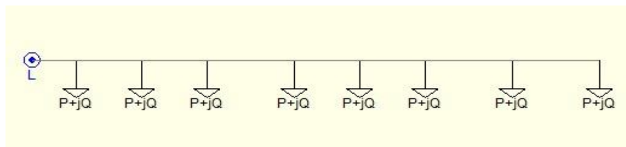

Fig.9. Load group1

Load group1 consists of eight loads as shown in Fig 9. They are named as 1.1 to 1.8 from left to right .They have different dynamic characteristics which are given in Table 3.

Overall DGS in PSCAD/EMTDC:

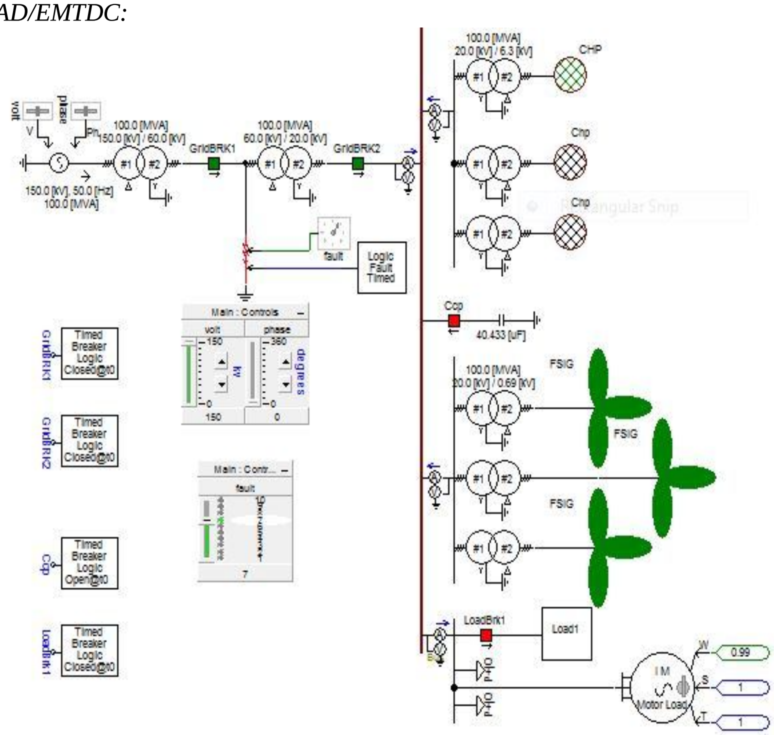

Fig.10. PSCAD model of DGS

IV. SIMULATION RESULTS AND DISCUSSIONS

In the studied scenario, the wind speed is assumed as the rated wind speed 16m/s, and a three-phase-ground fault occurs at 12 s, on the main grid side. After the fault lasts 150 ms, the DGS is islanded at 12.15 s. Then, the DGS would try to support its local loads with its own generations, that is, the three WTs and the three CHPs. The fast control strategy is applied to stabilize the DGS. Simulation is run for about 30 sand voltages and powers at various nodes are observed.

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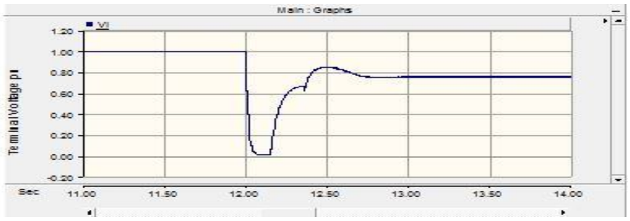

Fig.11. Terminal voltage of Bus-bar inpu

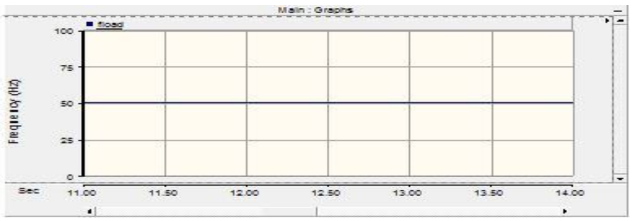

Fig.12. Bus-bar frequency in Hz

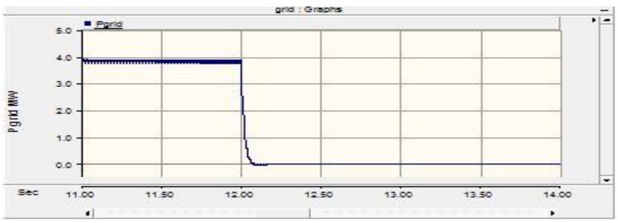

Fig.13. Active power from grid in MW

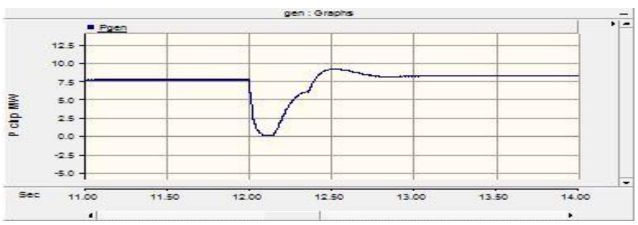

Fig.14. Active power from CHPs in MW

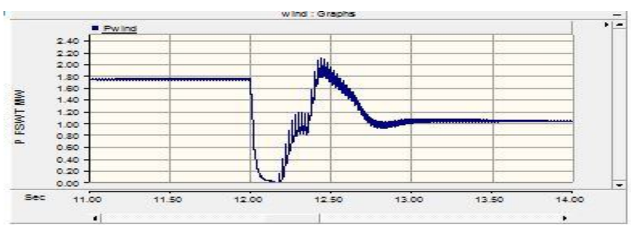

Fig.15. Active power from FSWTs in MW

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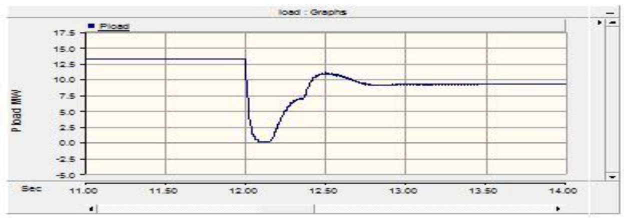

Fig.16. Active power drawn by loads in MW

Fig.17. Reactive power from grid in MVAR

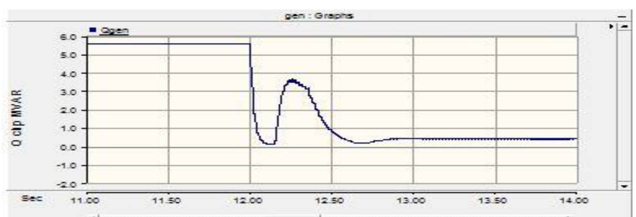

Fig.18. Reactive power from CHPs in MVAR

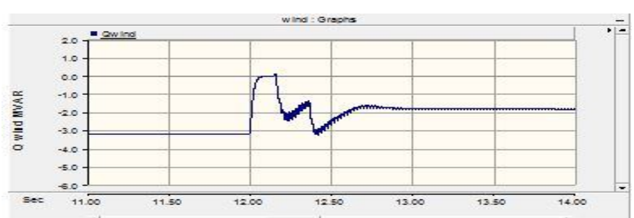

Fig.19. Reactive power from FSWTs in MVAR

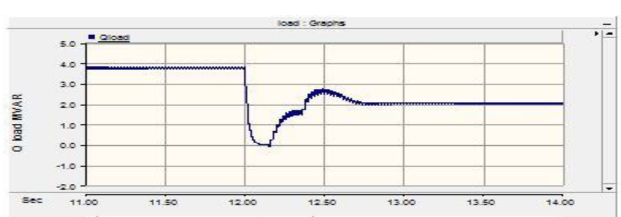

Fig.19. Reactive power drawn by Loads in MVAR

From the results, it is evident that voltage of the system is stabilized very fastly (<1sec).Here as the final stable voltage is less than 1pu, the voltage dependent load has decreased and load shedding case is not considered. We have considered only the simplest case only to verify the control strategy.

V. CONCLUSION AND FUTURE SCOPE OF WORK

Fast control strategy is proposed, the various components of the DGS are modelled in PSCAD/EMTDC and the system is simulated to demonstrate the fast control strategy. In this scenario, we haven't taken up load shedding operations. Future work can include detailed inclusion of load shedding operation and we can look for coordinated control that automates the system stabilization.

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