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Transient Stability Assessment of Hybrid Distributed Generation Using Facts Device

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ABSTRACT: *Due to increasing integration of new technologies into the grid such as hybrid electric vehicles, distributed generations, power electronic interface circuits, advanced controllers etc., the present power system network is now more complex than in the past. Consequently, the recent rate of blackouts recorded in some parts of the world indicates that the power system is stressed. The real time/online monitoring and prediction of stability limit is needed to prevent future blackouts.*

The aggravated increase in energy demand has posed a serious problem for the power system's stability and reliability, and hence has become of major concern. The shortcomings of conventional source of energy have paved way for renewable energy sources. The latter can form a part of a standalone system or grid connected system. A single renewable source of energy When integrated with other sources of energy it is termed as hybrid system. This thesis deals with PV, Wind, Hydro system. In this thesis an active power control strategy has been developed such that when the wind alone is not able to meet the energy demand, without compromising the frequency a transition occurs to wind diesel mode so that the energy demand is met. The mathematical model considered uses a STATCOM to meet the reactive power need upon sudden step change in power. The performance and the analysis is done in a user friendly MATLAB/Simulink environment.

Keywords: *Hybrid distributed generation, stability index, and critical clearing time. Wind turbine, Solar PV, Hydropower system, export, import, distributed generation*

I. INTRODUCTION

Distributed generation can be defined as a small capacity power plants based on either combustion based technologies, such as reciprocating engines and turbines, or non-combustion based technologies such as fuel cells, photovoltaic, wind turbines, etc[1]. These are located near the end–users and are characterized as renewable or co-generation sources [1]. Currently, there is wide-spread use of distributed generation across the globe though the level of penetration is still low [2]. By year 2020, the penetration level of DG in some countries such as USA is expected to increase by 25% as more independent power producers; consumers and utility company imbibe the idea of distributed generation [3]. However, the rapid progress in renewable energy power generation technologies, and the awareness of environmental protection have been the major reasons why alternative energy and distributed generation is a promising areas [4]. Because some of renewable energy sources can complement each other, multisource alternative energy systems have great potential to provide higher quality and more reliable power to consumers than a system based on a single source [5].

The larger the penetration level of hybrid distributed generation (HDG) in a power system, the more difficult it becomes to predict, to model, to analyze and to control the behavior of such system [5]. Some HDG using induction generators are not grid friendly because they consume reactive power instead of generating it. Most power converters do not have adequate control mechanism to actively support DG integration. The system inertia for some of them (e.g., solar PV or fuel cell) is extremely low. They are weather dependent with constant daily load variation [6]. Also, existing protection mechanism might not be able to take care of the problem of bi-directional power flow that takes place due to DG connection in radial networks. New design controllers are needed to effectively manage the multi-energy sources distributed generation in other to service remote villages. Due to the natural intermittent properties of wind and solar PV, stand alone wind/PV renewable energy systems normally require energy storage devices or some other generation sources to form a hybrid system. In an electrical power grid without energy storage, energy sources that rely on energy stored within fuels (coal, oil, gas) must be scaled up and down to match the rise and fall of energy production from intermittent energy sources. In this way the operators can actively adapt energy production to energy consumption in other to increase efficiency and lower the cost of energy production and to facilitate the use of intermittent energy sources.

In the USA the demand for electricity generation is mainly driven by price volatility i.e using distributed generation for continuous use or for peaking use (peak shaving) [3]. During seasonal changes, some energy sources might have to switch on during off peak hour while other during peak hour in other to reduce cost and enhance load balancing within the system. These configurations among many other things need to be investigated to know the dynamic interaction between the hybrids distributed generation and the grid .

II. DISTRIBUTION GENERATION AND HYBRID DISTRIBUTED GENERATION

The definition of distribution generation (DG) in the literature can be stated as follows: A small capacity power plant based on either combustion-based technologies such as reciprocating engines and turbines, or one combustion based technologies such as fuel cells, photovoltaic, wind turbines, located on or near end-users and are characterized as renewables or cogeneration non dispatched sources HDG is expected to form an active part of future power system network in order to meet the future increasing demand for energy.

The inherent potential to provide higher quality power, minimize power loss and produce more reliable power to consumers than a system based on a single source is the motivation behind the use of hybrid power generation. The objective of the integration is to capitalize on the strengths of both conventional and renewable energy sources, both cogeneration and non-cogeneration types. HDG can either be grid-connected or standalone system, renewable or nonrenewable system. HDG with one or more renewable (stochastic) or non-stochastic energy sources interact with the existing grid during import and export of power generation.

This interaction contributes different level of fault current, reactive power, different inertia, therefore making the system vulnerable to different instabilities compare to single energy source. Presently, the promising sources of hybrid distributed generation are wind generator, solar PV, fuel cell, micro-hydro, small hydro, biomass, geothermal, tides, wave generator. Wind generator and solar PV are the most commonly used.

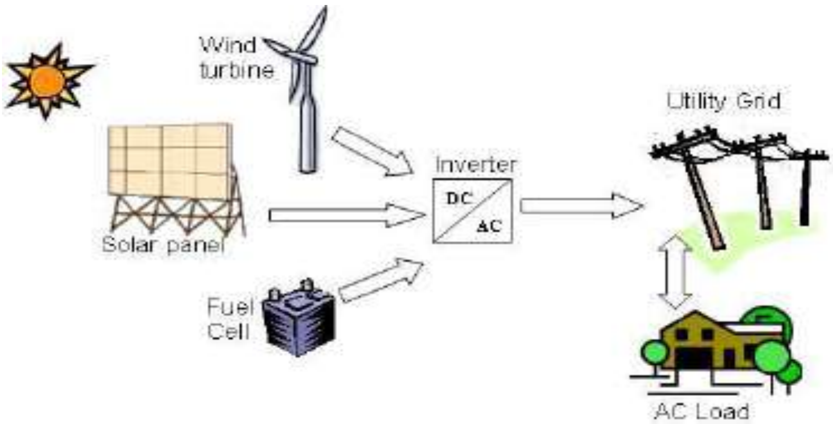

Fig.1. Representation of Distributed generation

III. MODELLING OF HYBRID DISTRIBUTED GENERATION

There are two methods described in literature for modeling renewable energy. They are time-step simulation methods [5] and probabilistic methods [6]. The time-step simulation is based on analytical method or deterministic approach of modeling. It goes through a simulation period step by step and the conditions are assumed to be known ahead of time. Generally, time-step simulation is deterministic approach where the fault application or other disturbances are fixed or set ahead of time. Probabilistic approach on the other hand is based on a stochastic method. It is good at processing stochastic uncertainties such as uncertainties about training data, type of fault and location of fault coupled with the conditions of the system . Probabilistic approach can be used with time-step simulation. Recently, computational intelligence (CI) techniques are gaining recognition in modeling and assessment of dynamic stability. This research is proposing the use of computational intelligence method in modeling and assessment of hybrid DG (HDG). This is relatively a new idea proposed in this thesis to determine transient stability margin of grid integrated HDG instead of using the time-step simulation or probabilistic method. CI techniques involve the use of data gathering and training. CI techniques can be combined with time-step simulation and also used with probabilistic method .

This section describes the modeling of wind generator, solar PV, and small hydropower system using analytical modeling approach. The reason for choosing the above three renewable generators is because they are available in abundance and environmentally friendly /Rather than standalone type distributed generators (DG), the utility interactive HDG [138] is considered which at the moment is gaining popularity.

There are two types of models in hybrid power generation .
1. Logistical models
2. Dynamic models

Logistical models are used primarily for studying long time performance, economic analysis, component sizing and prediction whereas dynamic models are used mainly for component design, assessment of system stability and power quality.

IV. SMALL HYDRO POWER PLANT

In a hydropower system, the energy present in water is converted into mechanical or electrical energy by the use of hydropower plant. Generic hydro power systems can be categorized in many different ways. Some of the methods of classification are based on how the electricity is generated by the plant, what kind of grid system is utilized for the distribution of electricity, the type of load capacity and the type of storage used by the system.Small hydro power plants are designed to generate electrical or mechanical power based on the demand for energy of the surrounding locality. In a typical SHS (Small Hydro-power System) the water from the source is diverted by weir through an opening intake into a canal (Fox, 2004) . A settling basin might sometimes be used to sediment

Based on the type of grid system, hydro power plants can be classified into local grid and extensive grid systems. In the local grid system, the electricity is generated and distributed only for the small locality, without use of any sophisticated electromechanical distribution systems. In contrast, in an extensive grid system, the electricity generated by the HPP (Hydro Power Plant) is loaded in a form of extensive grid such as the national grid system. Generally larger HPP (Hydro Power Plant) are of these types but in this study, focus is paid to the local grid sys-tem. Similarly, based on the load of the distribution system HPP (Hydro Power Plant) have been classified into base load plant and peak load plant but it is beyond the scope of this study; as the system designed in this thesis does not consider these factors

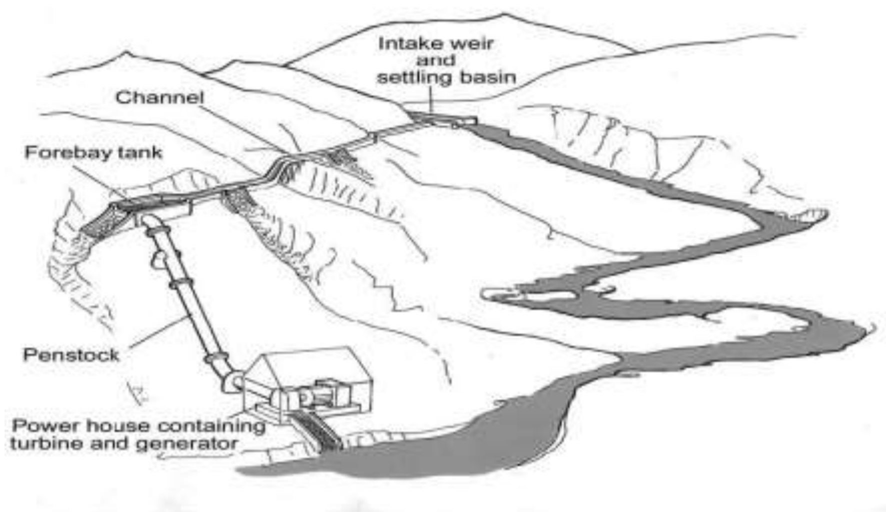

Fig. 2 A typical SHS (Small Hydropower System)

The power available in water current is proportional to the product of head and flow rate.
The general formula for any hydro power is $P_{hyd} = \rho g Q H$

P is the mechanical power produced at the turbine shaft (Watts), ρ is the density of water (1000 kg/m3), g is the acceleration due to gravity (9.81 m/s2), Q is the water flow rate passing through the turbine (m3/s), H is the effective pressure head of water across the turbine (m). The hydro-turbine converts the water pressure to mechanical shaft power, which further rotates the generator coupled on the same shaft. The relation between the mechanical and the hydraulic powers can be obtained by using hydraulic turbine efficiency ηh, as expressed by following equations:

$$P_n = \eta h \, P_{hyd}$$

$$Q = Av$$

And the whole equation is derive from Bernoulli's theorem which state

$$\frac{V^2}{2g} + h + \frac{p}{\rho g} = \frac{P_{hyd}}{\rho g Q}$$

Where v is the water flow speed (m/s), A is the area of the cross section (m2) p is the pressure of water (N/m2).
P = electrical or mechanical power produced, W
ρ = density of water, kg/m3
g = acceleration due to gravity, m/s2
H = elevation head of water, m
Q = flow rate of water, m3/s
η = overall efficiency of SHS (Small Hydropower system)

V. DOUBLY FED INDUCTION GENERATOR MODEL

In modeling the energy captured from the wind by the blades, disturbance imposed by the asymmetry in the turbine, the vortex tower interaction, and the mechanical Eigen swings in the blades are introduced in order to assert a more accurate behavior of wind energy conversion systems. The conversion system dynamic comes up from modeling the dynamic behavior due to the main subsystems of this system: the variable speed wind turbine, the mechanical drive train, and the PMSG and power electronic converters. The mechanical drive train dynamic is considered by three different model approaches, respectively, one mass, two-mass or three-mass model approaches in order to discuss which of the approaches are more appropriated in detaining the behavior of the system.

The power electronic converters are modeled for three different topologies, respectively, two-level, multilevel or matrix converters. The consideration of these topologies is in order to expose its particular behavior and advantages in what regards the total harmonic distortion of the current injected in the electric network. The electric network is modeled by a circuit consisting in a series of a resistance and inductance with a voltage source, respectively, considering two hypotheses: without harmonic distortion or with distortion due to the third harmonic, in order to show the influence of this third harmonic in the converter output electric current. Two types of control strategies are considered in the dynamic models of this book chapter, respectively, through the use of classical control or fractional-order control.

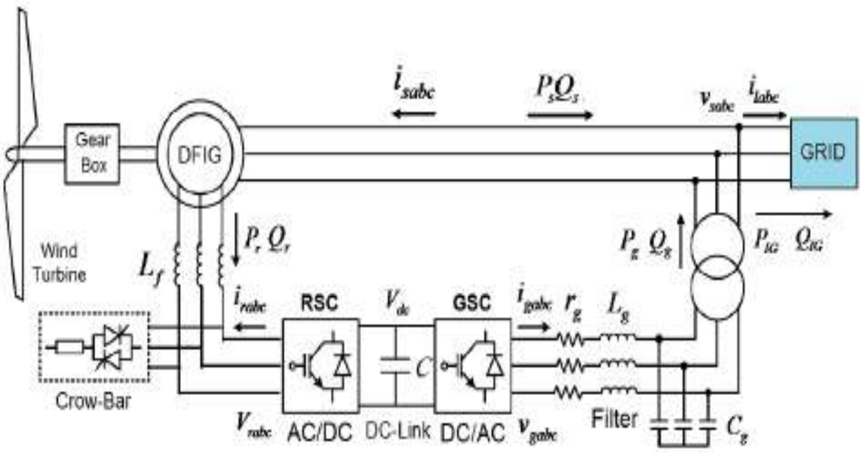

Fig.3 Configuration of a DFIG driven by a wind turbine.

DFIG driven by a wind turbine is shown in Fig. 3. The wind turbine is connected to the DFIG through a mechanical shaft system, which consists of a low speed shaft and a high-speed shaft with a gearbox in between. The wound rotor induction machine in this configuration is fed from both stator and rotor sides. The stator is directly connected to the grid while the rotor is connected to the grid through a converter.

Frequency to the utility grid for a wide operating range from sub synchronous to super synchronous speeds, the power flow between the rotor circuit and the grid must be controlled both in magnitude and direction. Therefore the converter consists of two four-quadrant IGBT PWM converters connected back to back by a DC link capacitor. The crow-bar is used to short circuit the rotor-side converter (RSC) to protect it from over current during transient grid disturbances.

VI. SHUNT DEVICE (STATCOM)

A D-STATCOM consists of a two-level VSC, a dc energy storage device, controller and a coupling transformer connected in shunt to the distribution network. Fig.4 shows the schematic diagram of D-STATCOM.

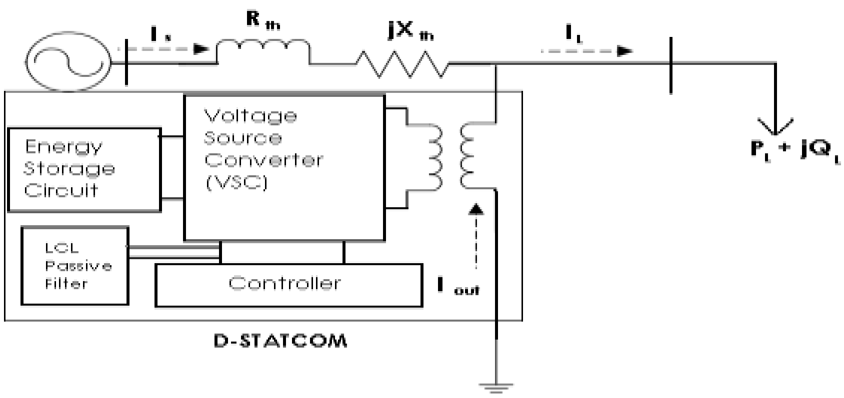

Fig. 4. Schematic diagram of a DSTATCOM

$I_{out} = I_L – I_S = I_L – ((V_{th} - V_L)/Z_{th})$ (1)

$I_{out} < \gamma = I_L < (-\theta) – (V_{th}/Z_{th}) < (\delta-\beta) + V_L/Z_{th} < (-\beta)$(2)

I_{out} =Output current

I_S = Source current

I_L = Load current

V_{th} = Thevenin voltage

V_L = Load voltage

Z_{th} = Impedance

Referring to the equation 2, output current, I_{out} will correct the voltage sags by adjusting the voltage drop across the system impedance, (Z_{th} ***=R+jX***). It may be mentioning that the effectiveness of D-STATCOM in correcting voltage sags depends on:

a) The value of Impedance, Z_{th} ***= R+jX***

b) The fault level of the load bus

In this case, PI controller will process the error signal to zero. The load r.m.s voltage is brought back to the reference voltage by comparing the reference voltage with the r.m.s voltages that had been measured at the load point. It also is used to control the flow of reactive power from the DC capacitor storage circuit.

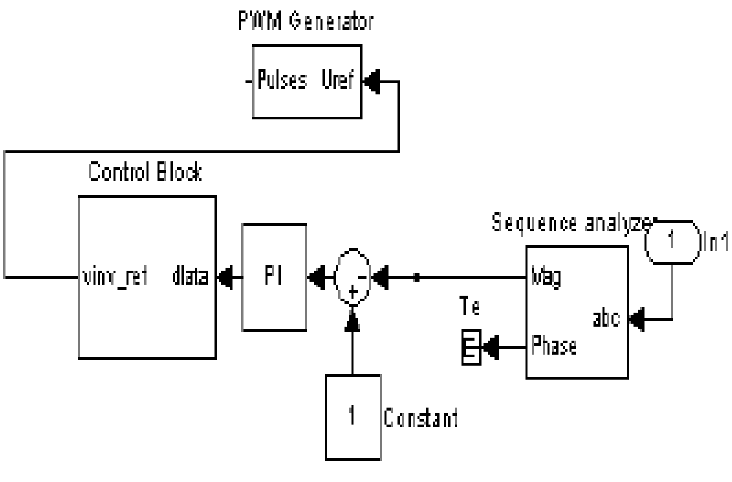

Fig. 5 Block diagram of Controller System

PWM generator is the device that generates the Sinusoidal PWM waveform or signal. To operate PWM generator, the angle is summed with the phase angle of the balance supply voltages equally at 120 degrees. Therefore, it can produce the desired synchronizing signal that required. PWM generator also received the error signal angle from PI controller. The modulated signal is compared against a triangle signal in order to generate the switching signals for VSC valves. Fig. 5. shows the block diagram of Controller system.The controller system is partially part of distribution system.

VII. SIMULATION RESULTS

A. Simulation Results for Hydro Power Plant

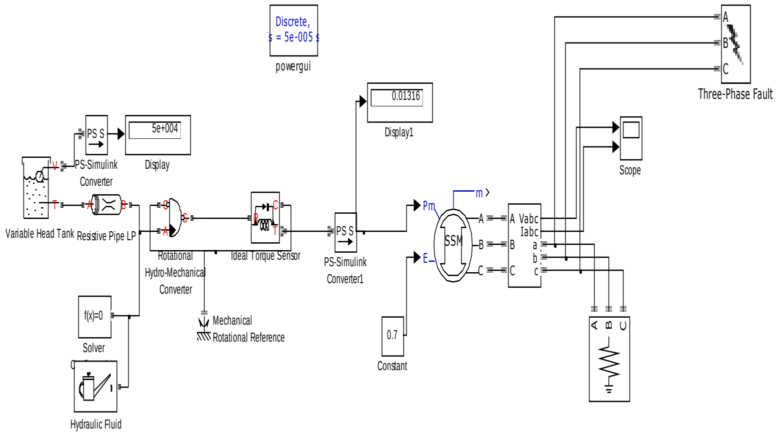

Fig .6 Simulation Circuit for Small Hydro Power plant

Fig .6 shows the small hydro power plant. A SLG fault is created at distribution level from 0.2 to 0.3 seconds.

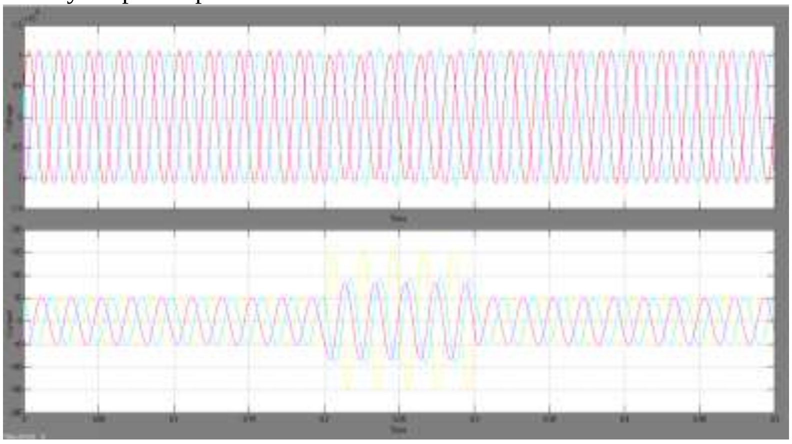

Fig .7 Voltage and Current waveform (Fault from 0.2 to 0.3 sec)

B. Simulation of Sloar Power Plant

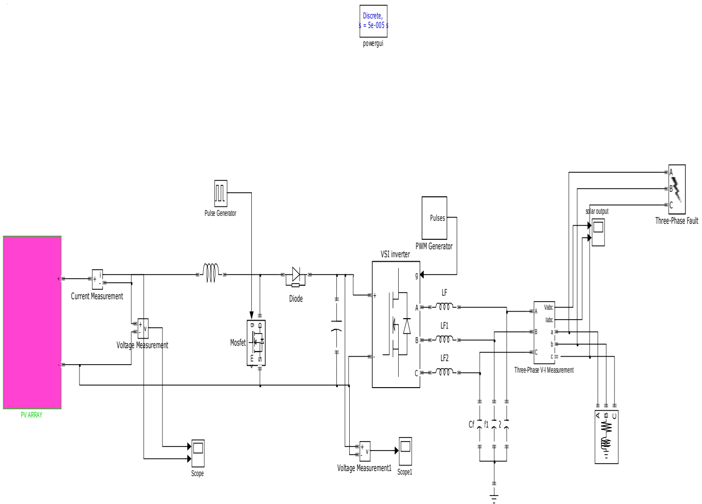

Fig .8 Simulation Circuit for Solar Power plant

Fig .8 the solar power plant. A SLG fault is created at distribution level from 0.4 to 0.7sec

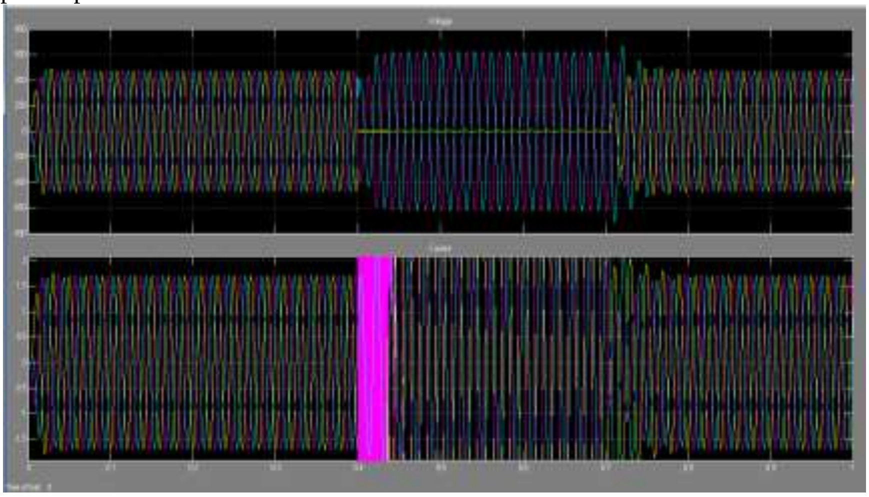

Fig .9 Voltage and Current waveform for SLG (Fault from 0.4 to 0.7 sec)

Fig .9 shows the voltage and current waveform. A single line to ground fault is created from 0.4 sec to 0.7 sec. Voltage observes a dip in the faulted phase and current wave observed a rise in that phase.

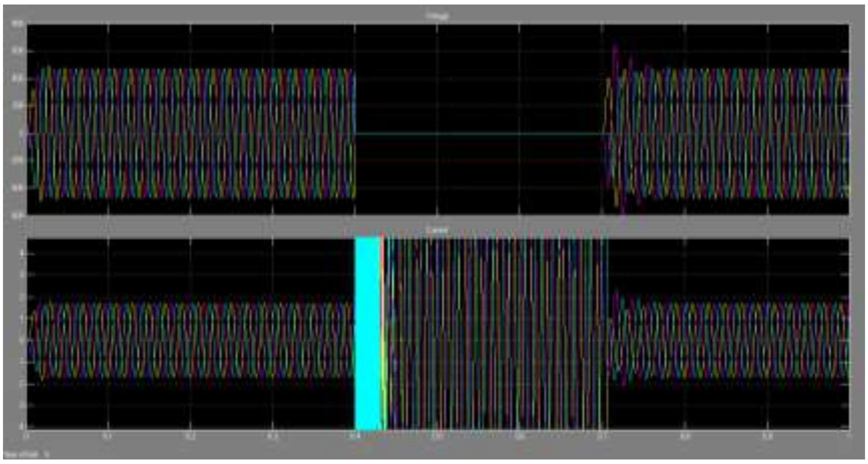

Fig 10 Voltage and Current waveform for Three phase fault (Fault from 0.4 to 0.7 sec)

Fig .10 shows the voltage and current waveform. A three phase fault is created from 0.4 sec to 0.7 sec. Voltage drops to zero and current rises to a very high value.

C. Simulation of Wind Power Plant

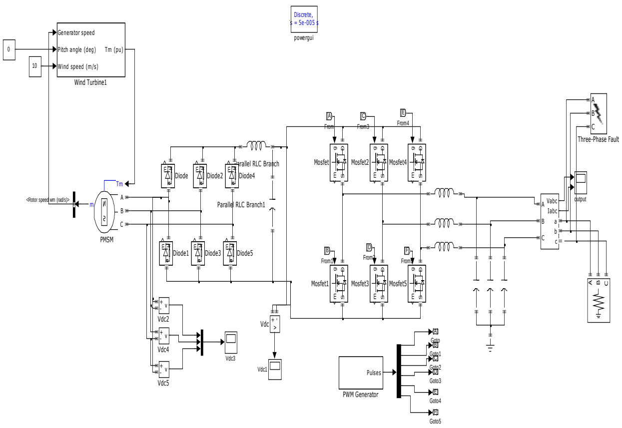

Fig .11 Simulation Circuit for Wind plant

The wind power plant. Different faults are created at distribution level from 0.3 to0.4 sec.

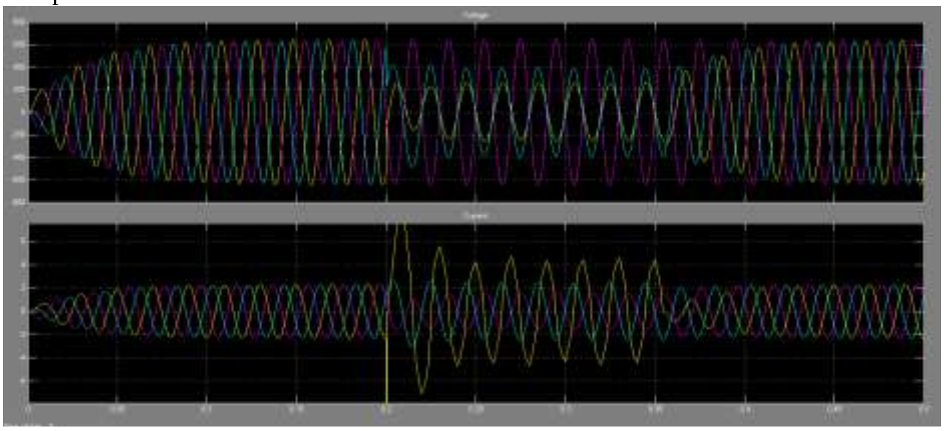

Fig .12 Voltage and Current waveform for SLG (Fault from 0.2 to 0.35 sec)

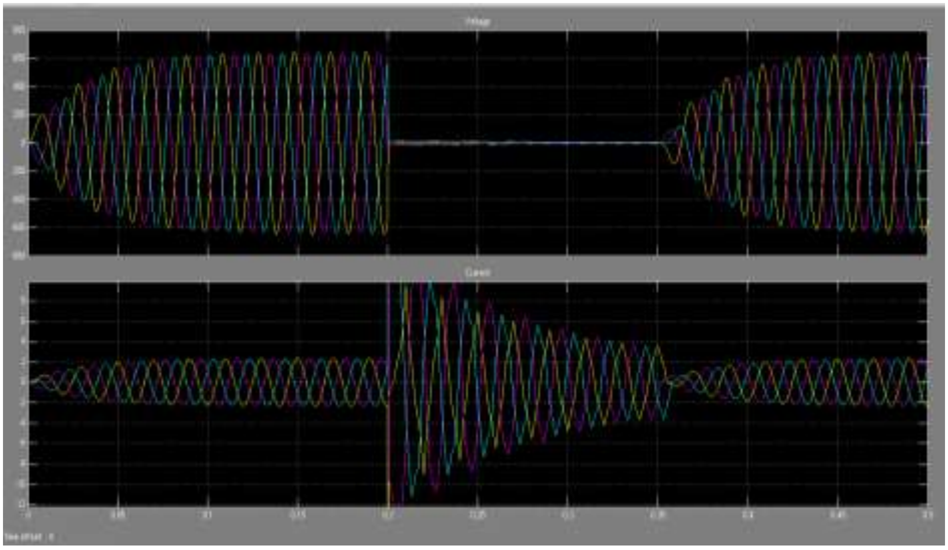

Fig .13 Voltage and Current waveform for three phase to ground fault (Fault from 0.2 to 0.35 sec)

D. Hybrid Power Plant

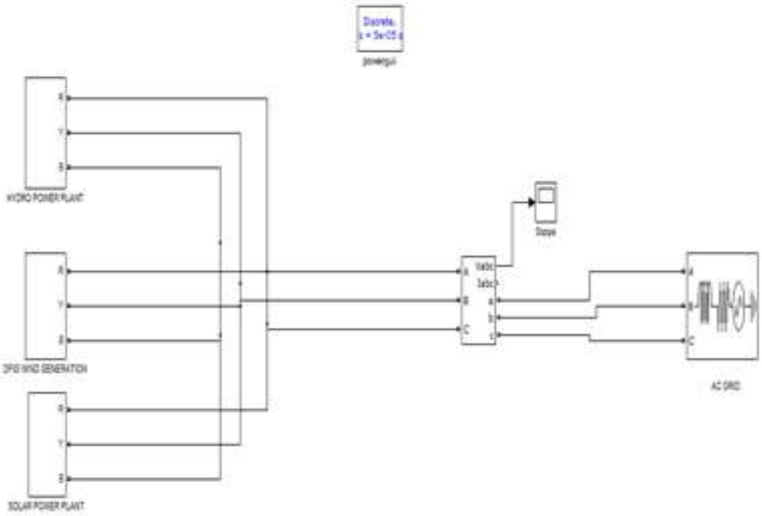

Fig.14 Hybrid Power Plant

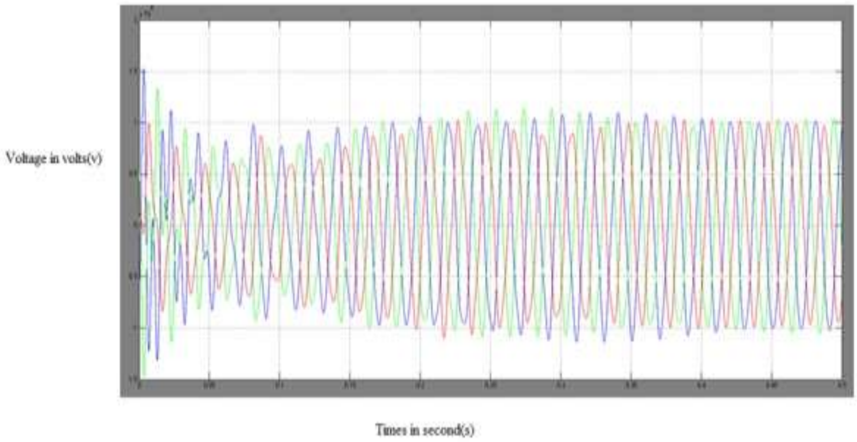

Fig.15 hybrid power without fault

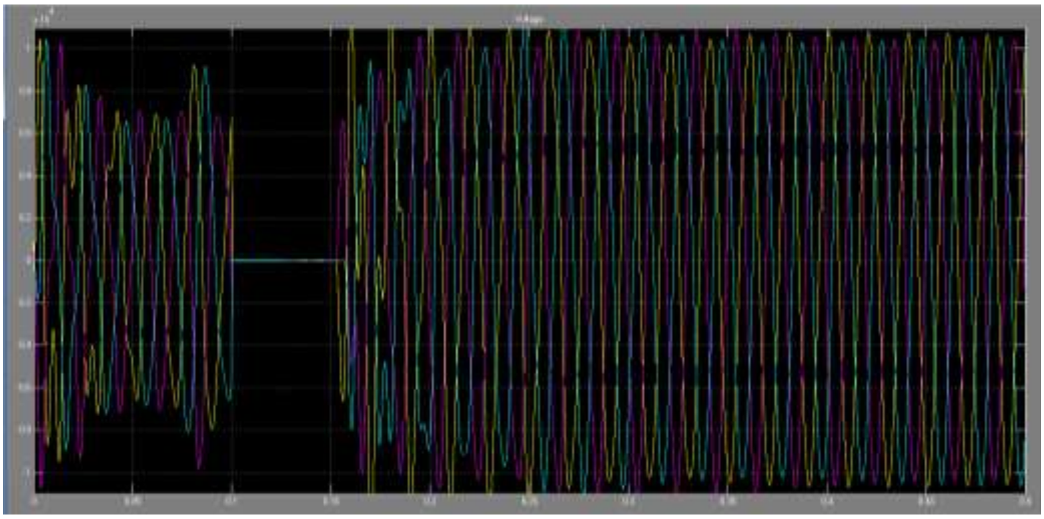

Fig. 16 hybrid power with fault

Hybrid Power Plant with STATCOM

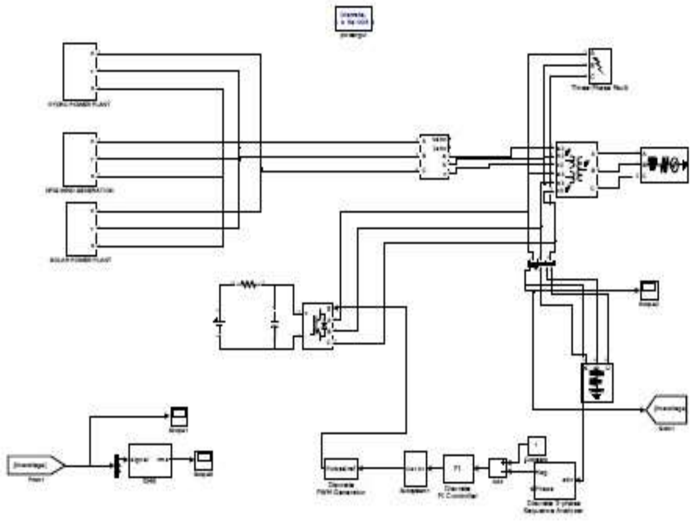

Fig.17 hybrid power plant with STATCOM

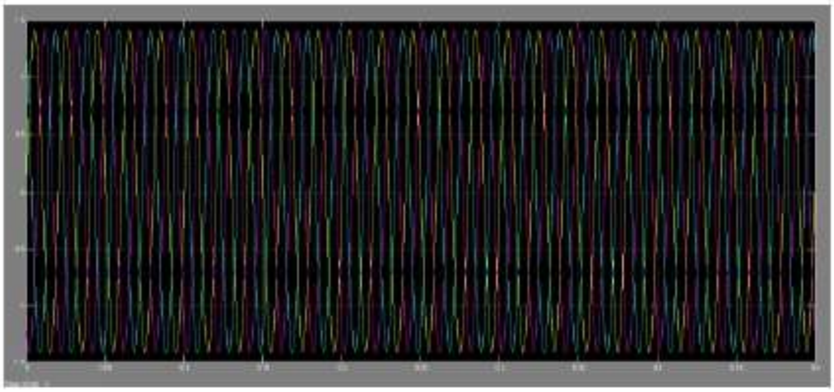

Fig .18 Voltage waveform for three phase to ground fault (Fault from 0.2 to 0.3 sec) with STATCOM

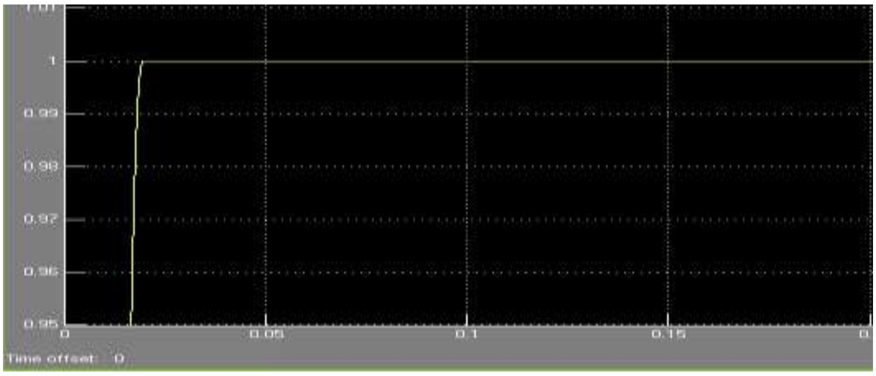

Fig .19 Per unit RMS graph of HDG with STATCOM

VIII. CONCLUSION

Modeling and simulation of grid integrated Hybrid distributed generation is simulated. It majorly investigates the impact of various complimentary energy sources on the power system network. The test system is single machine infinite system with integrated HDG. The system was observed by using oscillation duration and critical clearing time. The final report shows that, as the number of generator increases the stress on the system also increases. However, the simulation shows that hybrid power system with three generator show critical cases compared to two DG. The result shows that the impact depend on the network strength, level of penetration and the technologies involves.

I have simulated the hydro wind solar power plant with alone and hybrid distributed system. Modeling and simulation is done with renewable source. The output of three power plants is couple and simulated. Hybrid distributed of Hydro Solar and Wind power plant is connecting with AC Grid. The combination of three plant and outputs are shown in Mat lab simulation

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