INVESTIGATING THE TRANSIENT PERFORMANCE OF STRANDED WIND-DIESEL HYBRID POWER SYSTEM

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Abstract

This paper presents the transient performance of Wind-Diesel hybrid power system. Induction generator is used for wind power plant and synchronous generator is used for diesel system, combining both, named as hybrid system, is subjected to step load variation for analysing stability issues. The small signal model of synchronous generator with excitation system, induction generator of wind turbine and UPFC is obtained based on the requirement. The system reactive power is monitored and controlled by a Unified Power Flow Controller (UPFC) which improves the voltage profile of the system and thereby the stability. The system performance is investigated for both constant wind speed and varying wind speed. The complete system is modelled and built using MATLAB Simulink and the results are verified for various cases with and without UPFC controller.

Keywords: Induction Generator (IG), Synchronous Generator (SG), Unified Power Flow Controller (UPFC), Wind-Diesel Hybrid system, Diesel Generator set

I. Introduction

As the world's energy needs are increasing at a rapid pace, the dependency on alternative is energy is gaining popularity among policy makers. This situation has given a lot of scope has researchers to explore more through to bridge the gap. Alternative energy proves to be a clean energy which replaces the fossil fuels in near future. By saying so, the harvesting of renewable energy seems to be a uphill task; because of their interior nature. Also, bulk energy production by single unit is not so reliable, therefore many units along with conventional plant are used to provide a reliable and clean form of energy.
In this paper, a combination of wind turbine and diesel generator operate to serve a local load. The wind turbine consists of an induction generator and the diesel generator uses a synchronous generator with type-1 excitation control. This hybrid system is used to serve the load reliability without polluting the environment. Ref [IX] investigates the performance of wind-diesel hybrid power system for step change in input wind power and load demand. In this paper a static synchronous compensator is used to minimize this gap between reactive power generator and demand. The use of static VAR compensation to control reactive power in a hybrid wind-diesel power system is discussed in [VIII]. Pawan Sharma discussed the transient stability of wind-diesel hybrid system along with STATCOM which is used to control reactive power [XIV]. In [XII], the authors discussed about the effect of line varying component of wind speed such as gusting and periodic ramping in hybrid wind-diesel system. This paper shows that a simple excitation system can reduce the voltage oscillation to negligible levels. The authors in [XI] have discussed the vector control method of wind-diesel hybrid system to regulate the voltage and the power in the energy storage system. The dynamic and steady state operation of the wind-diesel system is discussed in [III]. The authors have discussed the modelling and vector control of DFIG used for both power generation sources.

In [VI], the energy storage system along with co-ordinated control is discussed to overcome the negative impact associated with variable power generation. Multimegawatt wind turbine system and its role in bulk power generation is discussed in [XVIII]. The authors reviewed various generators, control topologies and connectivity issues in this paper.

The authors in [XVI] have explained the management of various sources to meet the load. In this paper the wind generator plays an active role to meet the demand and also provides some ancillary services. Induction generators are commonly used in wind power plants due to its low cost, rugged construction and relative ease of control. Ref [II], [XVII], [VII] describes the use of induction generator and their modelling. The unbalance in reactive power consumption causes the system voltage to vary, which can be overcome by FACTS devices. The authors in [I], [X], [IV] discussed the effectiveness of STATCOM in controlling the reactive power thereby maintaining the system voltage.

This paper discusses the role of UPFC [VIII] to analyse the transient behaviour of the wind-diesel hybrid power system. The voltage variations are controlled by suitable reactive power injection during sudden removal of load and input wind changes.
II. Modelling Of Hybrid System Components

The hybrid system considered for analysis is shown in Fig. 1 to probe the performance analysis of a hybrid power system, an appropriate model of various components is to be established first.

A. Modelling Of Wind Turbine

Wind turbines are generally used to convert the kinetic energy in wind to mechanical energy and then to electrical energy using suitable generators. Induction generators are popularly used as generating units due to its asynchronous nature. Power Electronics converters are used together to control the active and reactive power flow from the generators.

The proposed system consists of an induction generator, based wind turbine, a diesel generator set comprising a synchronous generator with IEEE type 1 excitation and a reactive power compensator, UPFC with appropriate controller. The system is subjected to a step load change and therefore a reactive power imbalance exists which affect the system voltage. The reactive power balance equation from Fig. 1 is given by,

\[ Q_{SG} + Q_{UPFC} - Q_L - Q_{IG} = \cdots \cdots \cdots \cdots \cdots (1) \]

Where \( Q_{SG} \) = Reactive Power Generated from Diesel Generator Set.

Now suppose there is a sudden load change in the hybrid system, then there is an equal increment or decrement of reactive power in other components. The net reactive power change is given by,

\[ \Delta Q_{SG} + \Delta Q_{UPFC} - \Delta Q_L - \Delta Q_{IG} = \text{Surplus Power in the system} \cdots \cdots \cdots (2) \]

Due to this increment in reactive power, the system voltage gets affected and the change in voltage is expressed as,

\[ \Delta Q_{SG} + \Delta Q_{UPFC} - \Delta Q_L - \Delta Q_{IG} = \frac{2Em_p}{\sqrt{3}Q_S} \frac{d\Delta V}{dt} + \varphi_0 \Delta V \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots (3) \]
Let,

\[ \frac{E_{F1}}{Q_R} = \frac{1}{4\pi f K_m} = H_r \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (4) \]

Sub (4) in (3)

\[ \Delta Q_{SG} + \Delta Q_{UPFC} - \Delta Q_L - \Delta Q_{IG} = \frac{2H_R}{V^0} \frac{d\Delta V}{dt} + D_V \quad \ldots \quad \ldots \quad (5) \]

\[ D_V = \Delta \frac{Q_L}{\Delta V} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (6) \]

The amalgamated load can be expressed in the experiential voltage form as,

\[ Q_L = C_1 V_q \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (7) \]

Where \( C_1 \) is a load constant and \( q \) represent the type of load.

Therefore the Laplace form of the differential equation (6) is given by,

\[ \Delta V_V = \frac{k_v}{1 + s T_v} (\Delta Q_{SC}(s) + \Delta Q_{UPFC}(s) - \Delta Q_L(s) - \Delta Q_{IG}(s)) \ldots \quad \ldots \quad (8) \]

\[ T_v = \frac{2H_R}{D_v V} + \frac{1}{D_V} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (9) \]

**B. Modelling Of Diesel Generator**

In this hybrid power system consisting of wind-diesel power generation system, synchronous generators are usually used for DG sets. These generators supply reactive power whenever needed, to maintain a constant voltage of the power system. The synchronous generator is equipped with IEEE Type1 exciter which is represented in Laplace equations as follows:

\[ \Delta E_{F_d}(s) = \frac{\Delta V_3(s)}{K_{e3} + s T_{e3}} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (10) \]

\[ \Delta V_3(s) = \frac{K_a}{1 + s T_a} (\Delta V_V(s) - \frac{K_F}{T_F} \Delta E_{F_d}(s) + \Delta V_p(s)) \quad \ldots \quad \ldots \quad (11) \]

\[ \Delta V_p(s) = \frac{K_F}{T_F} \frac{1}{1 + s T_L} \Delta E_{F_d}(s) \quad \ldots \quad \ldots \quad (12) \]

The reactive power produced by the synchronous generator is represented by the following transfer function equations:

\[ \Delta Q_{SC}(s) = K_3 \Delta E_d^1(s) + K_4 \Delta V(s) \quad \ldots \quad \ldots \quad (13) \]

\[ K_3 = \frac{V e \cos \delta}{X_1} \quad ; \quad K_4 = \frac{E_1 e \cos \delta - 2V}{X_1} \quad \ldots \quad \ldots \quad (14) \]
For a small perturbation in the transient voltage, the flux linkage equations are given as follows:

\[
\frac{d}{d_t} (\alpha E_q) = \frac{\Delta E_{pq}}{\alpha} \Delta E_q \quad \cdots \cdots \cdots \quad (16)
\]

\[
(1 + sT_C) \Delta E_q (s) = K_1 \Delta E_{pq} (s) + K_2 \Delta V (s) \quad \cdots \cdots \cdots \quad (17)
\]

\[
T_C = \frac{x_d' T_1}{x_d}, \quad K_1 = \frac{x_d'}{x_d}, \quad K_2 = \frac{x_d' - x_d'}{x_d} \cos \theta \quad \cdots \cdots \cdots \quad (18)
\]

C. Modeling of Unified Power Flow Controller

Unified Power Flow Controller (UPFC) is an electrical device for providing fast-acting reactive power compensation on high voltage transmission line. UPFC has the capability to control real and reactive power flows on a transmission line and also improves power system stability. It is a combination of Static Synchronous Compensator (STATCOM) and a Static Synchronous Series Compensator (SSSC) which are connected through a dc link capacitor shown in fig2. Dc link capacitor is used to allow the real power flow between SSSC and STATCOM. Series connected SSSC and shunt connected STATCOM are providing concurrent real and reactive series line compensation without any external electrical source [V].

A Combination of shunt controller and series controller which works as a unified power flow controller is used to control power flow and this pair of converters can be operated in three modes: when shunt and series converters are interconnected through DC bus. If the switches of DC bus were disconnected, which is connected between shunt and series converter, then it has two modes additionally. Shunt converters controls the voltage and Series converter controls injected voltage in quadrature withcurrent. Shunt converters is used to supply active power demand of series converter through dc link. P_{sh} and Q_{sh} are real and reactive power of shunt voltage sources and P_{i}, Q_{i}, P_{j}, Q_{j} are real and reactive power of series voltage sources. The injected powers of shunt and series voltage sources are below:

Fig. 2: Single line Diagram of Unified Power Flow Controller
Multiply $V_j$ in above equations (23) and (24), will get

\[ P_j = \frac{V_i V_j}{x_{ij}} \sin \delta - \frac{V_j V_{m2p}}{x_{ij}} \] \hspace{1cm} (25)

\[ Q_j = \frac{V_i V_j}{x_{ij}} \cos \delta - \frac{V_j V_{m2p}}{x_{ij}} - \frac{V_i^2}{x_{ij}} \] \hspace{1cm} (26)

where

$V_{m2p} = V_j \gamma (i)$ and $V_{m2q} = V_j \beta (i)$

Take partial derivative for above equation

\[ \frac{dQ_j}{dt} = \frac{dQ_j}{d\delta} \frac{d\delta}{dt} + \frac{dQ_j}{dV_{m2p}} \frac{dV_{m2p}}{dt} \] \hspace{1cm} (27)

\[ \Delta Q_{UPFC} = K_f \Delta \delta (u) + K_r \Delta V (u) \] \hspace{1cm} (28)

III. Results and Discussions

The simulation results for the proposed UPFC system realized from the system utilizing STATCOM are discussed in the following section. The UPFC should maintain the voltage when there is sudden removal or increases in load. Transient is the behavior of the circuit after a certain action and this behavior will maintain for some time and it becomes steady state at $t$ tends to infinity. The behavior of complete system when sudden removal of load and sudden increases in load were explained with the help of reactive power and voltages in the system.
The above Fig.3 shows the complete simulink diagram of wind-diesel hybrid system. Table 1 shows the various parameters used for constructing the system.

**Table 1: Parameters of Induction Generator and Synchronous Generator**

| SYSTEM PARAMETERS | INDUCTION GENERATOR | SYNCHRONOUS GENERATOR |
|-------------------|---------------------|------------------------|
| Nominal Power     | 2500VA              | 2500VA                 |
| Voltage           | 440V                | 312V                   |
| Frequency         | 50HZ                | 50HZ                   |
| Speed             | 1500rpm             | 1 p.u                  |

Fig. 4 and 5 shows that performance of circuit when sudden removal of load at 0.3 sec. The real and reactive power becomes low after sudden removal of load at 0.3 sec as shown in figure 4(a) and there is also a change in voltages in figure 4(b). When the system is connected with UPFC, it will inject reactive power and it come back to flat position as shown fig 5(5) and voltage also becomes normal shown on Fig 5(b).
Fig. 5: (a) Voltage and Current 5(b) Real and Reactive Power with compensation

Fig. 6: (a) Voltage and Current 6(b) Real and Reactive Power without compensation

Fig. 7: (a) Voltage and Current 7(b) Real and Reactive Power with compensation

Fig 6 and 7 shows the behavior of the system when sudden increases in load after 0.3 sec. The reactive power is absorbed after 0.3sec in fig 6(a) and also there is a change in voltage as shown in fig 6(b). When the system connected to the UPFC then reactive power is injected there is a slight distortion for a small period of time (i.e. UPFC’s on time) and the reactive power becomes flat as shown in Fig 7(a) as well as voltage also becomes stable (in Fig 7(b)) after a small perturbation. Thus, the UPFC will provides the reactive power when there is a necessity in the system.

VI. Conclusion

The transient analysis of hybrid wind-diesel power system by using Unified Power Flow Controller (UPFC) has been discussed in this paper. An Induction generator has been considered for the wind turbine and synchronous generator with diesel set is considered for power generation. The system comprises of UPFC for reactive power support during load change. All the components namely the Induction generator, Synchronous generator with excitation system and UPFC are modelled for conducting the stability studies. Two cases like sudden removal of load and sudden increase of load is taken to see the effectiveness of UPFC based reactive power compensation.
compensation. From the simulation results it is evident that the system compensates the voltage drop by injecting reactive power using UPFC effectively.

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