Modeling and Simulation of Reactive Power Control of Wind-Diesel Hybrid System

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Abstract-This paper presents a wind-diesel hybrid system with controllers is taken for controlling main parameters of the system frequency and voltage, which determine the stability and quality of the supply. Voltage mismatch is the sole indicator of reactive power unbalance in the system. In this paper work a step disturbance is applied to wind-diesel system which disturbs the system frequency and voltage. Therefore a thorough investigation on wind-diesel hybrid system has been performed under stepped disturbance. First we have considered a IEEE type-I excitation system connected to wind-diesel hybrid system for controlling the terminal voltage of the system which is found insufficient for proper voltage control. A better control of the terminal voltage is obtained. However SVC is considered to be more efficient in meeting out any sudden change in reactive power demand and a better control of terminal voltage easily obtained. Mainly three types of SVC type-I, type-II and type-III systems have been thoroughly studied and simulated. Finally we compare the performance of SVC type-I, SVC type-II, SVC type-III it can be seen that the performance of SVC Type-II is best in comparison to SVC Type-I and SVC Type-III system.

Index term: - Diesel generator (D.G) set, induction generator (I.G), reactive power control, static var compensator (S.V.C), wind diesel hybrid system, synchronous generator (S.G) and Wind energy conversion system.

NOMENCLATURE.

\[ A, B \] System input, control, disturbance matrix, respectively.
\[ s, p \] State, control and disturbance vector respectively.
\[ E_m \] Electromagnetic energy stored in induction generator (I.G).
\[ \Delta E_m \] Small change in the stored electromagnetic energy.
\[ \Delta E_{eq} \] Small change in the voltages of the exciter, internal armature under steady state and transient conditions, respectively.
\[ K_n, K_i \] Voltage regulator,exciter, stabilizer, var regulator and thyristor firing gain constants, respectively.
\[ \eta \] Proportional and integral controller gain of var regulator, respectively.
\[ \eta_{IG} \] Performance index.
\[ \eta_{r} \] Efficiency of I.G.
\[ P_{in}, P_{IG}, Q_{IG} \] Real power input, real power generated and reactive power required by I.G respectively.
\[ P_{SG}, Q_{SG} \] Real and reactive powers generated by diesel generator (D.G),respectively.
\[ P_{r}, Q_{r} \] Real and reactive power load demand respectively.
\[ Q_{SVC} \] Reactive power generated by static var compensator.
\[ B_{SVC} \] Reactive susceptance of SVC.
\[ \Delta B_{SVC} \] Small change in reactive reactive susceptance of SVC.
\[ T_{av} \] SVC average dead time of zero crossing in the three phase system.
\[ T_{a} \] Thyristor firing angle.
\[ T_{a1}, T_{a2}, T_{a3}, T_{a4} \] Time constants lead-lag type of SVC regulator.
\[ a, b, c \] Thyristor-firing angle and nominal thyristor firing angle.
\[ \Delta \alpha \] Small deviation in thyristor firing angle.
\[ \alpha \] Power angle between voltage and armature EMF.
\[ r_x, x_2 \] Stator resistance and stator reactance.
\[ r_2, x_2 \] Rotor resistance and reactance referred to primary side.
\[ R_{eq}, X_{eq}, X_m \] Equivalent resistance, equivalent reactance, and magnetic reactance.
\[ S_{IG} \] Apparent power delivered by the IG.
\[ s \] Slip of IG.
\[ T_{ba}, T_{b1}, T_{b2} \] Exciter, stabilizer, and regulator time constants.
\[ T_{d} \] Direct -axis open circuit transient time constants.
\[ V \] System terminal voltage.
\[ \Delta V_{a}, \Delta V_{ref} \] Small change in terminal, reference, amplifier and feedback voltage.
\[ x_d \] Direct-axis reactance of synchronous generator.
\[ Q_r \] Rating of SVC.
\[ Q \] System reactive power rating.
\[ pu \] per-unit.

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1. INTRODUCTION

Electricity is one of the important ingredients for the development of modern society. The per capita electricity consumption of a particular community indicates its living status. However, everyone in the world is not lucky enough to have access to electricity. Even today there are still many locations in the world, which do not have an electrical connection to the central utility network. It may be due to remoteness, cost, or non-availability of sufficient grid power especially in the developing countries. The availability of sufficient electrical power for the upliftment of the society at these locations is very necessary and it could be generated locally both by conventional and non-conventional ways and with the combination of both. A power system which can generate and supply power to such locations is called by various names as remote, decentralized, stand-alone, autonomous, isolated power system, etc. The most common way to supply electricity to these loads is with diesel power plants. The main advantage of diesel system is that it is extremely proven technology and it is highly reliable, and maintained properly. For a small isolated diesel system the peak load may be as high as five times the average load. It is common for designers of the system to choose a diesel with a capacity of two times the peak load to provide a safety margin and room for future expansion of load. Such a system of its own will produce extremely costly electricity. The cost of electricity can be made comparable with the grid power by integrating diesel systems with other non-conventional energy systems (wind, small hydro, P.V etc.) depending upon sitting conditions.

In general, in any hybrid energy systems, there may be more than one type of electric generators [2]. In such circumstances, It is normal, although not essential for generators usually on the diesel to be synchronous, on the wind turbine to be induction [3]. An induction generators offers many advantages over a conventional synchronous generator as a source of isolated power supply. Reduced unit cost, ruggedness, brushless, absence of separate d.c source, ease of maintenance, self-protection against several overloads and short circuits [4]. A major disadvantage of an induction generator is that it require reactive power for it operation. In the case of a grid connected system an induction generator can get the reactive power from the grid/ capacitor banks, where as in case of hybrid system reactive power can only be supplied by capacitor banks/synchronous generator. In addition, generally, most of the loads are inductive in nature. The mismatch in generation and consumption of the reactive power can cause a serious problem of large voltage fluctuations at generator terminals. A detailed literature survey [5]-[10]. Shows that there is a great need to improve the reactive power control strategy of the hybrid system to maintain the voltage with in the specified limits. Controls, the system may be subjected to large voltage fluctuations, which is not desirable.

In this paper work a wind-diesel hybrid system is modeled and simulated while controlling main parameters of the system frequency and voltage, which is very crucial for system stability. Voltage mismatch is the sole indicator of reactive power unbalance in the system. In this paper work a step disturbance is applied to wind diesel system, which disturbs the system frequency and voltage [10]-[14]. Therefore, a thorough investigation on wind-diesel hybrid system has been performed under stepped disturbance. First, we have considered a IEEE type-I excitation system connected to wind-diesel hybrid system for controlling its terminal voltage, which is found to insufficient proper voltage control. However, SVC is considered to be more efficient in meeting out any sudden change in reactive power demand and a better control of the terminal voltage may be easily obtained. Therefore, we have taken static VAR compensator as a secondary source to control the reactive power of wind-diesel hybrid system. Mainly three types of SVC Type-I, Type-II and Type-III systems have been thoroughly studied and simulated. Finally, a comparative study of all these three types of SVC’s has been performed and it has been observed that the Type-II shows better performance than SVC Type-I and SVC Type-III systems.

II. MATHEMATICAL MODELLING OF WIND-DIESEL SYSTEM.

A wind-diesel system as shown in fig.1, is considered for mathematical modeling, where the SG considered with IEEE type-I excitation system connected on the DG set acts as local grid for the IG connected on the wind energy conversion system.

![Fig.1 Schematic diagram of general wind diesel hybrid system.](image)

The system also has an SVC to provide the required reactive power in addition to the reactive power generated by synchronous generator. SVC has fast response, provides continuous control of reactive power and offers a large number of advantages over conventional reactive power compensation schemes. In this paper work SVC is connected to wind-diesel hybrid system to control reactive power of the system. [15]. The excitation time constant is much smaller than the prime mover time constant, and its transient decays much faster does not affect the load frequency control (LFC) dynamic. Thus cross coupling between the (LFC) and automatic voltage regulator (AVR) loop is negligible. The reactive power balance equations under steady condition is

\[ Q_{SG} + Q_{SVC} = Q_r + Q_{IG} \]  (1)

Where \( Q_{SG} \) = reactive power generated by D.G set. (pu) kilovolt-amperes reactive; \( Q_{SVC} \) = reactive power generated by SVC (pu) kilovolt-amperes reactive; \( Q_r \) = reactive power load demand (per unit kilovolt-amperes reactive) and \( Q_{IG} \) reactive...
power generated by generator (per unit kilovolt-amperes)
For the incremental reactive power balance analysis of the
hybrid experience a reactive power load change of magnitude
$\Delta Q_L$. Due the action of AVR and SVC controllers, the system
reactive power increase by amount $\Delta Q_{SG}+\Delta Q_{SVC}$. The
reactive power required by the system will also change due to a
change in voltage by $\Delta V$. The net reactive power surplus in the
system, therefore, equals $\Delta Q_{SG}+\Delta Q_{SVC}-\Delta Q_L-\Delta Q_{IG}$, and this
power will also increase the system voltage by two ways:

1) By increasing the electromagnetic energy absorption
$(E_M)$ of the LG at the rate $d/dt(E_M)$:

2) By an increased reactive load consumption of the
system due to an increase in voltage.

This can be expressed mathematically as

$$\Delta Q_{SG}+\Delta Q_{SVC}-\Delta Q_L=\frac{d}{dt}(\Delta E_M)+D_V\Delta V.$$  \hspace{1cm} (2)

The electromagnetic energy stored in the LG is given by

$$E_M = \frac{1}{2}I_M \cdot L_M = \frac{1}{2}I_M (V/X_M)^2$$  \hspace{1cm} (3)

Where $I_M$, $L_M$ and $X_M$ are the current drawn, inductance
and reactance of the LG, respectively.

Equation (3) can be further written as

$$E_M = \frac{V^2}{4\pi f X_M}$$  \hspace{1cm} (4)

Where $f$ is the system frequency, from (4) $\Delta E_M$ can be written as

$$\Delta E_M = E_M - E_M^- = 2(E_M^- / \sqrt{V^2}) \Delta V$$  \hspace{1cm} (5)

Where $V^-$ and $E_M^-$ are the nominal values of terminal voltage
and electromagnetic energy stored in the LG. With increase in
voltage all the connected reactive-power-loads experience an
increase by $D_V = \partial Q_L / \partial V$ (per kilovolt-amperes reactive/per unit
kilovolt). The reactive power loads can be expressed in the
exponential voltage form as [8]

$$Q_L = C_1 V^q$$  \hspace{1cm} (6)

Where $C_1$ is the constant of the load, and the exponent $q$
depends upon types of load. For small perturbations, (6) can be written as

$$\Delta Q_L / \Delta V = q (Q_L \sqrt{V / V})$$  \hspace{1cm} (7)

Where $Q_L$ is the nominal value of the reactive power-load
demand. In (2) $D_V$ can be calculated empirically using (7).

Let $Q_R$ be the system reactive power rating.

using (5), (2) can be written as

$$\Delta Q_{SG}+\Delta Q_{SVC}-\Delta Q_L-\Delta Q_{IG} = 2E \sqrt{M} (V \sqrt{Q_R}) d/dt(\Delta V) + D_V \Delta V$$  \hspace{1cm} (8)

reactive). In (8), $Q_R$ divides only one term as the other terms are already
in pu kilovolt-amperes reactive. The term $E_M^- / Q_R$ can be written as

$$E_M^- / Q_R = 1/ (4\pi f R) = H_R$$  \hspace{1cm} (9)

Where $H_R$ is the constant of the system which has a unit of “s”
and $K_R$ is the ratio of the system reactive power of the system
reactive power rating to rated magnetizing reactive power of
IG. Substituting the value of $E_M^- / Q_R$(9)(8), we get.

$$\Delta Q_{SG}+\Delta Q_{SVC}-\Delta Q_L-\Delta Q_{IG} = 2H_R V \frac{d}{dt}(\Delta V) + D_V \Delta V$$  \hspace{1cm} (10)

In Laplace form, the state differential equation from (10) can be written as

$$\Delta V(s) = K_V (1+sT_V) \times [\Delta Q_{SG}(s) + \Delta Q_{SVC}(s) - \Delta Q_L(s) - \Delta Q_{IG}(s)]$$  \hspace{1cm} (11)

Where $T_V = 2H R / D_V V$

and

$$K_V = 1/D_V$$  \hspace{1cm} (12)

Under transient condition,$Q_{SG}$ is given by [14]

$$Q_{SG} = (E' V \cos \delta - V^2)/X_a.$$  \hspace{1cm} (13)

For small perturbation, (14) in Laplace

$$\Delta Q_{SG} = (V \cos \delta X_a) \Delta E + (E' V \cos \delta - 2V)/X_a.$$  \hspace{1cm} (15)
Laplace transfer function (15) can be written as
\[ \Delta Q_{SG}(s) = K_3 \Delta E'q(s) + K_4 \Delta V(s) \]  
(16)

Where
\[ K_3 = \left( \frac{V \cos \delta}{X'd} \right) \]  
and
\[ K_4 = \left( \frac{E'_q \cos \delta - 2V}{X'd} \right) \]  
(17)
(18)

The reactive power supplied by the SVC is
\[ Q_{SVC} = V^2 B_{SVC} \]  
(19)

For small perturbation, eq. (19) in Laplace can be written as
\[ \Delta Q_{SVC} = K_6 \Delta V(s) + K_7 \Delta B_{SVC}(s) \]  
(20)

Where
\[ K_6 = 2VB_{SVC} \]
\[ K_7 = V^2 \]  
(21)

The block diagrams with SVC type-II and type-III can be obtained by replacing upper portion of fig 3 with fig. 2b, 2c respectively.

III. TRANSIENT RESPONSES OF THE WIND-DIESEL SYSTEM.

In this paper work, transient response of wind diesel hybrid system have been thoroughly studied and simulated. Three types of SVC configurations for reactive power control are considered along with the IEEE type-I excitation control system connected to wind-diesel hybrid system. And their transient response time is compared in terms of first swing time and then settling time.
Fig 1.a-c, 2.a-c, 3.a-c Transient responses of wind-diesel hybrid system with SVC type-I, SVC type-II, SVC type-III respectively for a 1% step increase in reactive power load.

Comparative study of wind-diesel hybrid system.

<table>
<thead>
<tr>
<th>System Parameter</th>
<th>SVC Type-I</th>
<th>SVC Type-II</th>
<th>SVC Type-III</th>
</tr>
</thead>
<tbody>
<tr>
<td>∆Q&lt;sub&gt;SG&lt;/sub&gt;</td>
<td>0.8 sec.</td>
<td>0.15 sec.</td>
<td>0.4 sec.</td>
</tr>
<tr>
<td>∆Q&lt;sub&gt;IG&lt;/sub&gt;</td>
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<td>∆Q&lt;sub&gt;SVC&lt;/sub&gt;</td>
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IV CONCLUSION.

In this paper work a step disturbance is applied to wind-diesel system which disturbs the system frequency and voltage. Therefore a thorough investigation on wind-diesel hybrid system has been performed under stepped disturbance. First we have considered a IEEE type-I excitation system connected to wind-diesel hybrid system for controlling the terminal voltage of the system which is found insufficient proper voltage control. A better control of the terminal voltage is obtained. However SVC is considered to be more efficient in meeting out any sudden change in reactive power demand a better control of terminal voltage easily obtained. Mainly three types of SVC type-I, type-II, type-III systems have been thoroughly studied and simulated. Finally we compare the performance of SVC type-I, SVC type-II, SVC type-III it can be seen that the performance of SVC Type-II is best in comparison to SVC Type-I, SVC Type-III system.

REFERENCES


