REACTIVE POWER AND SYSTEM FREQUENCY RELATIONSHIP: A CASE STUDY

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ABSTRACT

This paper describes the impact of System frequency on Reactive power. The discussion is based on the study of these two important parameters on generator, urban radial load and SVC. In Northern India wide variation in frequency, in the range of 48.5 - 50.2 Hz, is observed against the permissible limit of 49 - 50.5 Hz in the absence of free governor mode of operation (FGMO). Studies show that relation of Reactive power with respect to frequency is negative. One percent increase/decrease in frequency causes 6-12 % decrease/increase in Reactive power . To minimize this variation in Reactive power , for better Reactive power management, system stability and voltage control, a tighter frequency band is an urgent need today.

Key Words: Reactive Power, Frequency, Load Modelling.

1. INTRODUCTION

An effective Reactive power management should address three basic requirement in any power system. First, it must maintain voltage within predefined limits at all voltage levels, both under normal and contingency conditions. Second, it seeks to minimize congestion of real power flows and third, it seeks to minimize power losses. It is meant to control generation, absorption & flow of Reactive power at all voltage levels in the system. Reactive power is a function of voltage which itself follows the frequency.

Thus, it is not only the voltage but also the frequency[1], which plays a significant role in Reactive power change. There is lot of literature available on voltage control which are being adopted in most of the power system in the developed countries where frequency is almost constant. But in India, where frequency varies in wide range, the present voltage control techniques, which are based on control of Reactive power , are inadequate due to voltage and frequency dependency. It is found that for addressing voltage problems, it is essential to address frequency problem.

In this paper, three case studies have been performed using real time data. In first case study, continuous and scatter graphs of frequency and Reactive power are plotted *(fig. 3.1 & 3.2)* for the generating units of Rihand-I. Secondly, an urban industrial radial load of Okhla is studied and analyzed. The trends of Active and Reactive power with respect to frequency for a week in the month of April'08 is shown*(fig. 4.1 - 4.5)* . Third, response of SVC located at Kanpur is captured against frequency *(fig. 7.1 & 7.2)*. Based on these studies, an attempt has been made to estimate the impact of system frequency variation on Reactive power for Northern Region as a whole.

2. REACTIVE POWER RESOURCES

Reactive power sources can be categorised as Dynamic & Static. Synchronous condenser, power electronics devices such as SVC, FACTS,etc. are some important dynamic sources of Reactive power while reactor, capacitor, transmission lines, transformer tap changers fall under category of static sources.

Dynamic sources provide fast, continuously controllable reactive support. Capacitor and inductor are not variable and offer control only in large steps.Lines loaded below SIL generates reactive power while ones loaded above SIL absorb it.

3. Frequency Response Of Generator

Generating stations in the grid are connected together for optimum utilisation. Frequency in the system increases or decrease due to imbalances in generation and demand. This change in frequency affects the reactive power capability of the generators.

EMF generated by the generator is a function of flux and frequency.

$$E \quad = \quad 4.44\, f\, Ø\, n$$

During change in frequency the induced EMF is kept constant by changing flux but in practice, this is not ideally adjusted due to many reasons and EMF becomes directly proportional to frequency.

MVAR absorption by the generator is high when frequency is high and vice versa. Scatter plot (Fig.3.2) of MVAR and frequency also support this trend. This corroborates the fact that requirement of MVAR in the grid is following the frequency.

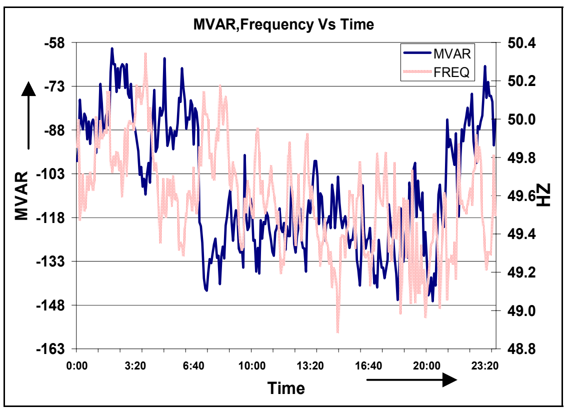


Fig.3.1
Continuous Plot: Freq.Vs MVAR
(Generator at Rihand)

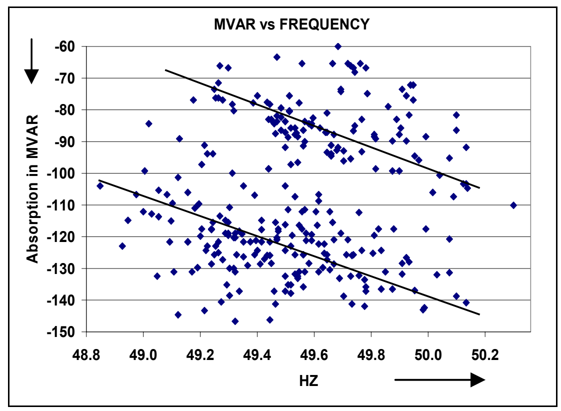


Fig.3.2
Scatter Plot: Freq.Vs MVAR
(Generator at Rihand)

4. Frequency Response Of Load

Case Study Of Urban Radial Load

Sensitivity of frequency on Active and Reactive power of load is studied for 220 kV OKHLA industrial area in South of New Delhi.The station under study is connected to Northern region grid and feeding the load radially through 220/66 kV and 220/33 kV transformers. The load of this area is predominantly industrial with some mix of commercial & residential load. Data of Active & Reactive power, voltage and frequency was recorded at load terminal for a week in the month of April'08.

This data is processed in two ways, first on whole day basis and second for a selected time. Table I shows daily slope values of dP(%)/dF(%), dQ(%)/dF(%) on whole day and selected time basis, for the whole week.
Where,

$$\mathbf{dP = (P-P_o)/\,P_o,}$$
$$\mathbf{dQ = (Q-Q_o)/\,Q_o,}$$
$$\mathbf{dF = (f-f_o)/\,f_o}$$

Table-I

Trends for Active and Reactive Power with Frequency(y=dP(%),dQ (%)and x=dF(%))				
	Whole day		Selected time	
Date	dP(%)/dF(%)	dQ(%)/dF(%)	dP(%)/dF(%)	dQ(%)/dF(%)
23-Apr-08	y = 1.96x	y = -5.56x	y = 1.16x	y = -8.19x
24-Apr-08	y = 0.56x	y = -8.44x	y = 1.08x	y = -11.5x
25-Apr-08	y = 0.28x	y = -9.91x	y = 0.84x	y = -11.1x
26-Apr-08	y = 0.38x	y = -10.09x	y = 1.24x	y = -6.87x
27-Apr-08	y = 1.55x	y = -7.67x	y = 1.11x	y = -6.25x
28-Apr-08	y = 1.50x	y = -10.75x	y = 0.69x	y = -9.71x
29-Apr-08	y = 1.08x	y = -8.12x	y = 1.11x	y = -7.32x

The period witnessing minimum switching and transient disturbances was considered while studying data on *Selected Time* basis. Thus, the sensitivity of load on voltage and frequency could be analyzed more accurately.

It is found that in both the cases, the slope of Active power Vs frequency is positive while Reactive power Vs frequency is negative. Studies showed that one percent increase/decrease in frequency causes 6% to 12% decrease/increase in MVAR.

For Whole day

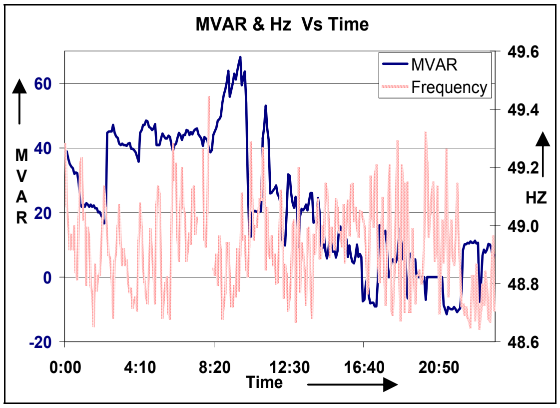


Fig.4.1
Continuous Plot: Freq. Vs MVAR
(Radial Load of Okhla)

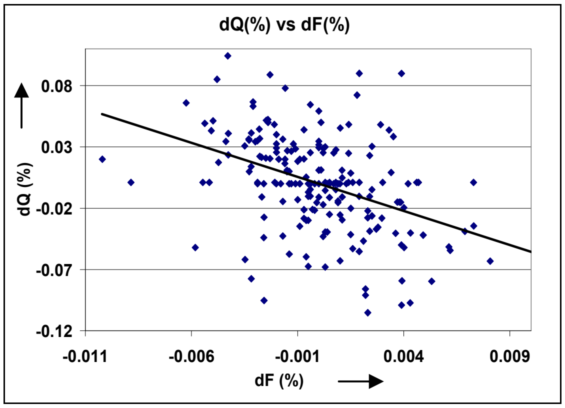


Fig.4.2
Scatter Plot: Freq. Vs MVAR
(Radial Load of Okhla)

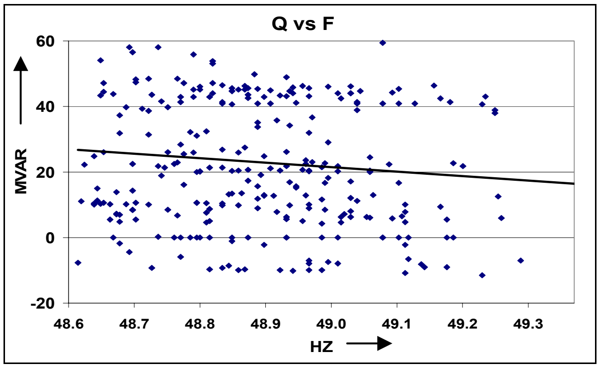
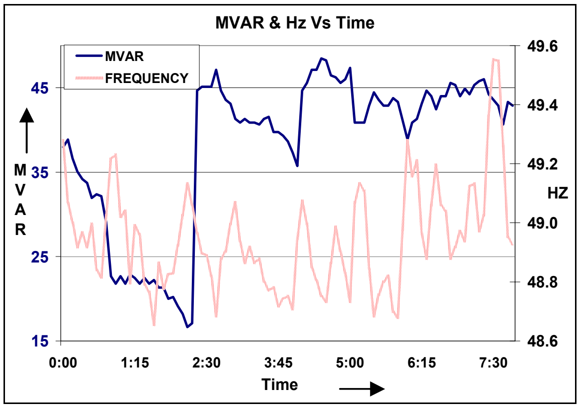


Fig.4.3
Scatter Plot: Freq. Vs MVAR
(Radial Load of Okhla)

For Selected Time



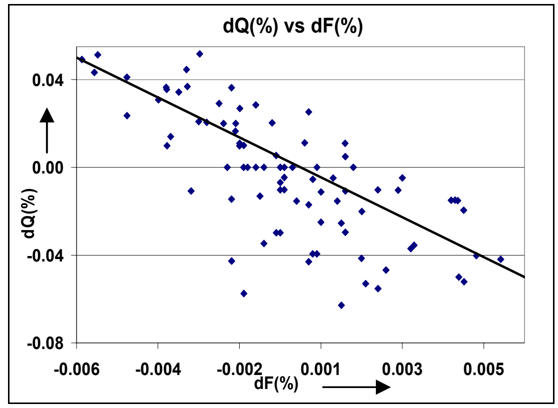
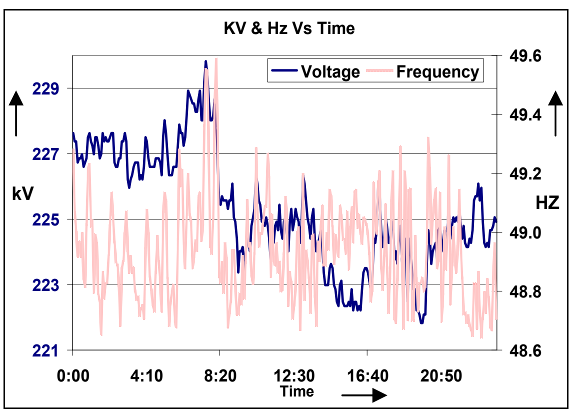


Fig.4.4
Continuous Plot: Freq. Vs MVAR
(Radial Load of Okhla)

Fig.4.5
Scatter Plot: dQ Vs dF
(Radial Load of Okhla)

5. IMPACT OF FREQUENCY ON VOLTAGE

To visualise the relation of frequency and voltage, graph between voltage and frequency for the same radial load is plotted *(Fig. 5.1 & 5.2)*.



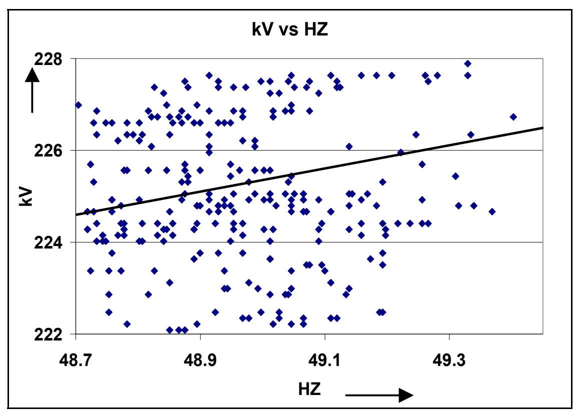


Fig.5.1
Continuous Plot: Freq. Vs Voltage
(Radial Load of Okhla)

Fig.5.2
Scatter Plot: Voltage Vs Freq.
(Radial Load of Okhla)

A rising trend of voltage with frequency was observed *(Fig. 5.1 & 5.2)*. It clearly indicates that composite load is dependent on both voltage and frequency.

6. LOAD MODELLING

The Transmission planning criteria[3] adopts following load model:

(I) $P = P_o(f/f_o)$
(II) $Q = Q_o(V/V_o)^2$

This model of load Q i.e. Reactive demand of load is frequency independent, for composite load model as per IEEE Committee Report [4] frequency dependence and voltage dependence terms are introduced.

$$P(V,f) = (a_1V^{n1}f^{m1}+a_2V^{n2}f^{m2}+a_3V^{n3}f^{m3})P_o$$

$$Q(V,f) = (a_4V^{n4}f^{m4}+a_5V^{n5}f^{m5}+a_6V^{n6}f^{m6})Q_o$$

The coefficients a_1 through a_6 are normally associated with load categories such as general residential,industrial and agriculture load.However,the coefficients are fractions which sum to unity.

$$a_1+a_2+a_3 = 1.0$$
$$a_4+a_5+a_6 = 1.0$$

The exponents permit considerable flexibility in characterising such load categories.

7. SVC's Response on Voltage and frequency

The response of SVC installed at Kanpur is showing in Fig 7.1 & 7.2.

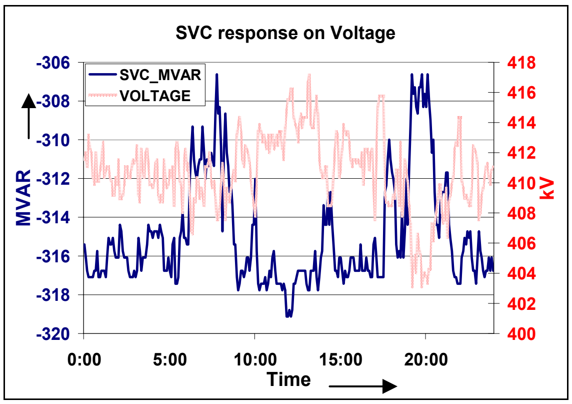


Fig.7.1
Continuous Plot: MVAR Vs Voltage
(SVC installed at Kanpur)

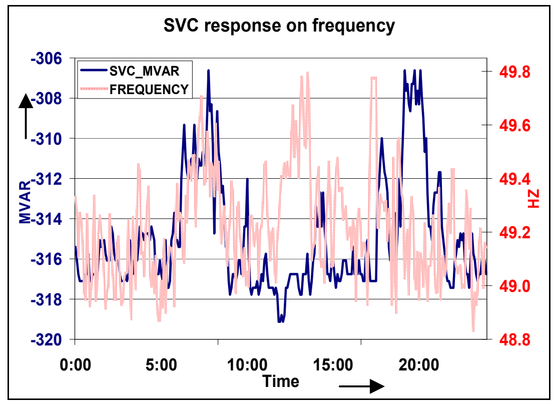


Fig.7.2
Continuous Plot: MVAR Vs Freq
(SVC installed at Kanpur)

It is observed that SVC response, both to the voltage & frequency variation, almost in the same pattern i.e. higher MVAR absorption when voltage/frequency increases and vice versa.

8. Scenario of Reactive Power in Indian Power System:

Indian Electricity Grid Code 2003[5], allows frequency variation, in the range of 49 to 50.5 HZ , while in developed countries frequency is kept constant. India's grid is divided into five region out of which four (except Southern Grid) are synchronized. Table-II shows the Country's region wise reactor and capacitor in MVAR as .

Table-II

Regionwise Reactor/Capacitor Capacity(MVAR)			
Region	**Line Reactor**	**Bus Reactor**	**Capacitor**
NR	2593	2773	22339
WR	1365	2551	15587
ER	2760	1397	
SR	1901	762	16032
NER	300	544	175
Total	**8919**	**8027**	**54133**

Case Study Of Northern Region (NR)

The demand of the Northern Region is approximately 30,000 MW. Assuming power factor the 0.9, the Reactive power requirement is 14500 MVAR ($Q = P \tan(\cos^{-1}(0.9))$). From the case study of Radial load, it is found that, one percent increase/decrease in frequency, decreases/increases 6 to 12% MVAR.

Frequency variation of 1 Hz, from system frequency of 50 Hz, is not uncommon in India. This 2 % increase/decrease in frequency would cause 12 to 24% decreases/increases in MVAR. Thus, for Northern region one Hz frequency increase/decrease would additionally require apprx. 1750 to 3500 MVAR.

Typical rating of reactors installed in the region is 31.5/50/63/80 MVAR. Assuming the switchable reactor rating of 50 MVAR, 1750-3500 MVAR change, caused by frequency variation alone, shall be equivalent to switching **35-70** no. of reactors .

This observation is very significant for planning and operation purpose. Normally, while planning for the Reactive power, voltage variation becomes the principal driver. Frequency variation tend to take the back seat. This paper proposes frequency variation as another important factor, which must be considered while doing Reactive power planning. From the operator point of view, handling such a large variation in Reactive power due to wide variation in frequency is a very challenging task. If not controlled properly, system would begin to face High/Low voltages problem and associated ill effects like voltage collapse etc.

9. Physical Interpretation

Composite load consists of static load, a generic dynamic recovery load and an aggregate induction motor load.Static load represent all the static part of the load.Generic recovery load is to account the effect of all down stream on line tap changer OLTC,and thermo-statically controlled heating load.An aggregate induction motor is used to represent all downstream compressors and other rotating load.

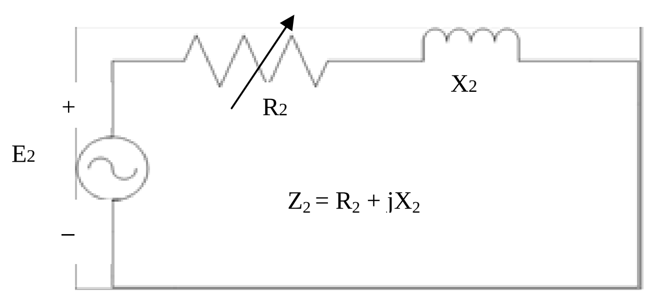


Fig.9.1

Fig.9.1 shows the Induction motor rotor equivalent circuit where R_2 and X_2 are rotor resistance and reactance values.

When the rotor runs ,its impedance Z_2 changes with change in system frequency, as rotor reactance vary in direct proportion to the system frequency[6]. Thus increase in rotor reactance will cause less absorption in Reactive power .

10. Limitation of Measurements

The data for the above study is taken from the real time telemetered data recorded at Northern Region Load Dispatch Centre in New Delhi using a conventional SCADA system. The measurements have inherent limitations of various devices. Transducers installed have accuracy of 0.1 – 1 % while RTUs 0.25 %. Sampling rate of data recorded in the SCADA system is 10 seconds, which is considerably large from the point of view of frequency response.Nevertheless,it is good enough for this study.

Load demand varies with the weather i.e seasonal change,lifestyles,state of economy and others factors.Above study is assuming same weather throughout the discussion.

11. PAST STUDIES

In past, many studies have been done to recognize the behaviour of load under varying voltage and frequency conditions. Static characterstics, Voltage dependency, frequency dependency,dynamic characterstics, load composition, component characterstics, network characterstics were studied.

Eminent Power System Engineer Mr.C.Concordia and Mr.S.Thara[1], has performed series of experiments, to find the frequency dependency of load .In this study,various slope values dP/dV,dP/dF,dQ/dV and dQ/dF, were calculated for different components like incandescent lamps,Air conditioner,Home appliance with motor etc.The study was also carried out for Residential,Commercial, Industrial & Agriculture load in winter and Summer,and composite load of NY,Germany,Poland,small & large towns etc..

Important observation from the test results and measured load charactetstics [1] show that dP(%)/dV(%), dP(%)/dF(%), dQ(%)/dV(%) are all positive varying from 0.6 to 0.2. Where as dQ(%)/dF(%) is negative and vary in the range of -1.2 to -5.The above finding of the test results are also substantiated by the fact that low voltages are related to low frequency and high voltages are due to high frequency.Results of dQ(%)/dF(%) for residential,commercial and industrial load is tabulated in Table III [1].

Table-III

Measured Load Characterstics			
Load and Remarks		Year	dQ(%)/dF(%)
Residential Load in Summer	3.5 MVA	1980	-15 to -0.5
Residential Load in Winter	4.5 MVA	1980	-23 to -3
Commercial Load Downtime Business	28 MVA	1972	-1.3
Industrial Load, Aluminium Plant	132 MVA	1972	0.7

Although type of load has changed over the time,impact of frequency variation on Reactive power can still be observed ,as evident by our studies also.

12. CONCLUSION

Efficent voltage control and Reactive power management both are required for system reliability and power transfer across the transmission network. Above study of generator and radial load clearly shows the strong impact of frequency on Reactive power. Practically,it seems that small frequency deviation from the system frequency causes appreciable change in Reactive power.So,to have a good voltage profile, permissible frequency band must be minimized.

In present scenario of india, where the frequency band is 49 Hz to 50.5 Hz, Q-F relationship cannot be ignored. It becomes all the more important in the system where variations in voltage and frequency are high. There is also an urgent need of frequency dependent composite load modelling at planning as well operational stage.

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BIODATA

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