A STUDY FOR THE RELIABLE PENETRATION OF A 4.5MW WIND FARM INTO THE LOCAL POWER GRID OF SITIA-CRETE

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Abstract

In recent years, considerable interest exists in using wind sources to generate electric energy. Unfortunately, wind is not always available and conventional sources must supply the demand during these quiescent periods. Clusters of wind generators, penetrating the utility grid, usually tend to disturb the quality performance characteristics. In the present paper, load-flow and power system stability studies were performed in order to evaluate the impact of the penetration of a 4.5MW wind farm to the local grid. The results show that the above wind energy penetration level will not cause any problem to the existing electric power grid.

INTRODUCTION

There is considerable interest in using novel methods to generate electric energy, including wind, tidal and solar sources. The main reason is that the conventional fuels are limited and expensive, whereas the above mentioned new forms, generally known as renewable, are unlimited and cheap to operate, although their first installation is rather expensive. Wind power, potentially, is one of the most promising renewable energy sources in Crete, the largest Greek island.

Many parts of the island are identified as high wind potential sites. The region of Sitia, as shown in Figure 1, is estimated to be of the highest wind potential ones. Moreover, it presents a special site interest, because the most windy locations are not situated in complex terrain or at high altitudes. For that reason, the municipality of Sitia-Crete is interested to examine the possibility of installing a 4.5MW wind farm. The Technical University of Crete was involved to that project. For the purposes of this study, the exact data were used for (a) the high voltage power transmission lines, (b) high voltage grid substations and (c) the electric power production units. All the above consist the electric system of the Public Power Corporation (PPC), currently existing on the island.

THE WIND GENERATOR POWER GRID INTERFACE

The power grid of Crete is of autonomous type (not interconnected to the rest national power system) and its topology is depicted in Figure 2. The Wind Electric Conversion Systems (WECS) of 4.5MW totally, consisting of small asynchronous units (100..-300kW), is considered to penetrate the power system, interconnected to the high voltage bus of Sitia. The WECS design must assure the unidirectional power flow from the wind generator units to the power system. Also, suitable protection devices have to be incorporated, to maintain safe operation in the event of fault conditions, either on the side of the WECS or the side of the power grid.

The normal operation of the power grid-load system presumes that certain constraint parameters are maintained within predetermined limits. The most significant constraints, from an operational and safety viewpoint, are :

1. The voltage variation, at any point along the grid system, should not exceed +-5% of its nominal value.

2. The maximum permanent system frequency variation may not exceed +-1.5Hz. In addition, the maximum value of the rate of the frequency variation may not exceed +-1.5Hz/sec.

3. The WECS power introduced into the grid, at any time instant, may not exceed the difference between the load demand and a minimum permitted power level from the power station, under which the operation of the conventional generators is interrupted.

Load flow and frequency control simulation models were developed, to evaluate the impact of the 4.5MW WECS penetration to the local grid of Sitia-Crete, under various loading conditions [1]. Brief description of the models is provided below, to clarify the method used.

1. *The Load-Flow Program* [1]

A modified Load-Flow routine is employed in order to simulate efficiently the steady state behavior of the power system. The characteristics of the transmission networks and the loading conditions of each bus are used as input data to the program. Then the program computes the admittance of each power line, the bus impedance levels, the real and the reactive component of the complex power along each line, the line losses, as well as the voltage level of each bus.

2. *The Frequency Control program* [1]

The operational characteristics of the asynchronous generation units allow for the WECS units to be considered as "negative load", as far as the power system is concerned. Thus, a transfer function representation of the power control mechanisms, for a multiple generation system, can be established [1]. Any load disturbance ΔP_L results in a change of system frequency Δf. Each generation unit contributes an output power change ΔP_G, so that the frequency will be brought back to its nominal level.

The speed controller performs two functions : (a) a primary control function, which brings the system to an equilibrium state with a permanent frequency error ΔF_{stat} and (b) a secondary control, which establishes eventually nominal rotational speed, thus eliminating the static frequency error. From the transfer function representation of the power control mechanisms, a state variable formulation and a fourth-order Runge-Kutta routine are employed leading to a determination of the maximum frequency variation for a given load disturbance, the permanent frequency variation following primary frequency control as well as the rate of the frequency variation.

SIMULATION RESULTS - CONCLUSIONS

1. *Load-Flow study of the interconnected system*

First, a load-flow simulation study is performed, under maximum and minimum loading conditions for the power grid, with the total WECS capacity removed. The results of this simulation are listed in Table 1 for maximum loading and Table 2 for minimum loading conditions.

Then, the load-flow simulation study for the maximum and minimum loading conditions of the power grid, with the total WECS capacity interconnected, is performed. The results of this simulation are shown in Table 3 for maximum loading and Table 4 for minimum loading conditions.

A comparison for the bus voltage levels both, between Tables 1-3 and 2-4, proves that the voltage variation, at any point along the power grid, due to the WECS penetration, is around +-1% for maximum and around +-1.5% for minimum loading conditions.

2. *Frequency Stability study of the interconnected system*

For the frequency stability study, it is assumed that the instantaneous introduction or removal of the total WECS cluster capacity, constitutes the "worst case" conditions for the frequency control calculations.

The simulation results from the frequency control model, when the total WECS capacity is suddenly disconnected, are listed in Table 5 and depicted in Figure 3. The case (a) corresponds to maximum, whereas the case (b) to minimum loading conditions, when total WECS capacity was disconnected.

The maximum and permanent (static) frequency variations, as well as the rate of the frequency variations, are shown.

The results above show that the bus voltage variations at any point along the power grid, the maximum permanent system frequency variation and the maximum frequency rate variation are maintained well within the predetermined limits. Therefore, even under the worst conditions, ie. during wind gusts or abrupt changes in WECS output power, the 4.5MW wind farm can penetrate the power grid of Sitia-Crete without degrading of the normal operation of the power grid. Thus the project seems to be attractive, from the power grid reliability point of view.

REFERENCES

1. G. J. Vachtsevanos, K. C. Kalaitzakis, "Penetration of Wind Electric Conversion Systems into the Utility Grid", IEEE Trans. on PAS, Vol PAS-104, No 7, July 1985.

2. W. Stevenson "Elements of Power System Analysis", Mc Graw Hill, 1975.

BUS RESULTS

Bus	Type	V_mag (kV)	θ (rad)	Ps (kW)	Qs (kVAr)	Pg (kW)	Qg (kVAr)
1	slack	150.000	0.000	126635.949	75467.989	0.000	0.000
2		151.720	0.002	58500.000	43875.000	36600.000	22683.000
3		65.068	-0.009	0.000	0.000	37700.000	23364.000
4		148.765	-0.008	0.000	0.000	28100.000	17415.000
5		146.911	-0.014	0.000	0.000	12200.000	7561.000
6		145.598	-0.020	0.000	0.000	13400.000	8305.000
7		144.057	-0.027	0.000	0.000	11400.000	7605.000
8		143.528	-0.029	0.000	0.000	12000.000	7436.000
9		142.392	-0.034	0.000	0.000	7400.000	5486.000
10		149.877	-0.006	0.000	0.000	17600.000	10907.000
11		151.170	-0.002	0.000	0.000	7100.000	4400.000
12		142.392	-0.034	0.000	0.000	0.000	0.000

LINE RESULTS

Line	S_bus	E_bus	I_mag (A)	P_line (W)	Q_line (VAr)
1	1	2	39.13	28189.20	61750.21
2	3	1	681.63	316228.31	691432.48
3	1	4	222.22	91853.33	370865.99
4	1	5	201.99	286019.57	696472.80
5	1	6	261.89	527399.79	1283905.99
6	6	7	153.67	108152.28	263064.70
7	7	8	58.54	14120.38	34375.94
8	5	8	104.35	160912.84	391764.86
9	8	9	64.69	32557.70	79302.77
10	1	10	40.33	8394.70	36375.90
11	2	10	108.86	53204.65	230482.66
12	2	11	55.25	9678.42	41918.79
13	12	9	0.00	0.00	0.00

Table 1. Load-Flow results under maximum loading conditions with the WECS disconnected.

BUS RESULTS

Bus	Type	V_mag (kV)	θ (rad)	Ps (kW)	Qs (kVAr)	Pg (kW)	Qg (kVAr)
1	slack	150.000	0.000	15597.975	8026.478	0.000	0.000
2		150.584	0.001	13135.000	9851.000	7400.000	4586.000
3		65.876	-0.001	0.000	0.000	5100.000	3161.000
4		149.835	-0.001	0.000	0.000	3800.000	2355.000
5		149.613	-0.002	0.000	0.000	1600.000	991.000
6		149.454	-0.003	0.000	0.000	1600.000	991.000
7		149.252	-0.004	0.000	0.000	1800.000	1116.000
8		149.195	-0.004	0.000	0.000	1500.000	930.000
9		149.064	-0.005	0.000	0.000	1000.000	620.000
10		150.082	-0.001	0.000	0.000	3900.000	2417.000
11		150.506	0.001	0.000	0.000	1000.000	620.000
12		149.064	-0.005	0.000	0.000	0.000	0.000

LINE RESULTS

Line	S_bus	E_bus	I_mag (A)	P_line (W)	Q_line (VAr)
1	1	2	13.99	3605.02	7897.01
2	3	1	91.08	5646.42	12345.89
3	1	4	29.84	1655.84	6685.61
4	1	5	25.83	4676.56	11387.67
5	1	6	33.25	8502.04	20697.44
6	6	7	20.66	1954.73	4754.60
7	7	8	6.47	172.49	419.92
8	5	8	13.25	2594.04	6315.54
9	8	9	7.89	484.48	1180.07
10	1	10	6.31	205.53	890.60
11	2	10	30.06	4055.92	17570.27
12	2	11	7.82	193.74	839.12
13	12	9	0.00	0.00	0.00

Table 2. Load-Flow results under minimum loading conditions with the WECS disconnected.

BUS RESULTS

Bus	Type	V_mag (kV)	θ (rad)	Ps (kW)	Qs (kVAr)	Pg (kW)	Qg (kVAr)
1	slack	150.000	0.000	121887.552	71488.268	0.000	0.000
2		151.720	0.002	58500.000	43875.000	36600.000	22683.000
3		65.068	-0.009	0.000	0.000	37700.000	23364.000
4		148.765	-0.008	0.000	0.000	28100.000	17415.000
5		147.198	-0.013	0.000	0.000	12200.000	7561.000
6		146.018	-0.018	0.000	0.000	13400.000	8305.000
7		144.719	-0.024	0.000	0.000	11400.000	7605.000
8		144.404	-0.026	0.000	0.000	12000.000	7436.000
9		143.967	-0.028	0.000	0.000	7400.000	5486.000
10		149.877	-0.006	0.000	0.000	17600.000	10907.000
11		151.170	-0.002	0.000	0.000	7100.000	4400.000
12		144.290	-0.027	4500.000	3375.000	0.000	0.000

LINE RESULTS

Line	S_bus	E_bus	I_mag (A)	P_line (W)	Q_line (VAr)
1	1	2	39.13	28189.20	61750.21
2	3	1	681.63	316228.31	691432.48
3	1	4	222.22	91853.33	370865.99
4	1	5	184.41	238394.80	580503.97
5	1	6	238.39	437012.53	1063866.57
6	6	7	130.45	77943.56	189586.38
7	7	8	35.77	5272.76	12836.48
8	5	8	86.93	111664.46	271862.79
9	8	9	25.00	4862.40	11843.64
10	1	10	40.33	8394.70	36375.90
11	2	10	108.86	53204.65	230482.66
12	2	11	55.25	9678.42	41918.79
13	12	9	38.98	5565.29	13550.21

Table 3. Load-Flow results of the interconnected system (WECS connected) under maximum loading conditions.

BUS RESULTS

Bus	Type	V_mag (kV)	θ (rad)	Ps (kW)	Qs (kVAr)	Pg (kW)	Qg (kVAr)
1	slack	150.000	0.000	11095.769	4643.844	0.000	0.000
2		150.584	0.001	13135.000	9851.000	7400.000	4586.000
3		65.876	-0.001	0.000	0.000	5100.000	3161.000
4		149.835	-0.001	0.000	0.000	3800.000	2355.000
5		149.869	-0.001	0.000	0.000	1600.000	991.000
6		149.826	-0.001	0.000	0.000	1600.000	991.000
7		149.846	-0.001	0.000	0.000	1800.000	1116.000
8		149.987	-0.001	0.000	0.000	1500.000	930.000
9		150.513	0.001	0.000	0.000	1000.000	620.000
10		150.082	-0.001	0.000	0.000	3900.000	2417.000
11		150.506	0.001	0.000	0.000	1000.000	620.000
12		150.821	0.003	4500.000	3375.000	0.000	0.000

LINE RESULTS

Line	S_bus	E_bus	I_mag (A)	P_line (W)	Q_line (VAr)
1	1	2	13.99	3605.02	7897.01
2	3	1	91.08	5646.42	12345.89
3	1	4	29.84	1655.84	6685.61
4	1	5	9.88	683.84	1665.19
5	1	6	12.04	1114.69	2713.61
6	6	7	1.93	17.13	41.66
7	7	8	14.91	915.65	2229.14
8	5	8	3.10	141.57	344.67
9	8	9	29.51	6776.91	16506.92
10	1	10	6.31	205.53	890.60
11	2	10	30.06	4055.92	17570.27
12	2	11	7.82	193.74	839.12
13	12	9	37.30	5093.67	12401.93

Table 4. Load-Flow results of the interconnected system (WECS connected) under minimum loading conditions.

RESULTS	
dF max -> -0.072 Hz	dF max -> -0.145 %
dFstat -> -0.048 Hz	dFstat -> -0.095 %
dF/dt max -> -0.130 Hz/sec	

(a) Under maximum loading conditions.

RESULTS	
dF max -> -0.124 Hz	dF max -> -0.247 %
dFstat -> -0.069 Hz	dFstat -> -0.138 %
dF/dt max -> -0.192 Hz/sec	

(b) Under minimum loading conditions.

Table 5. Interconnected system frequency stability study when the WECS are rejected suddenly.

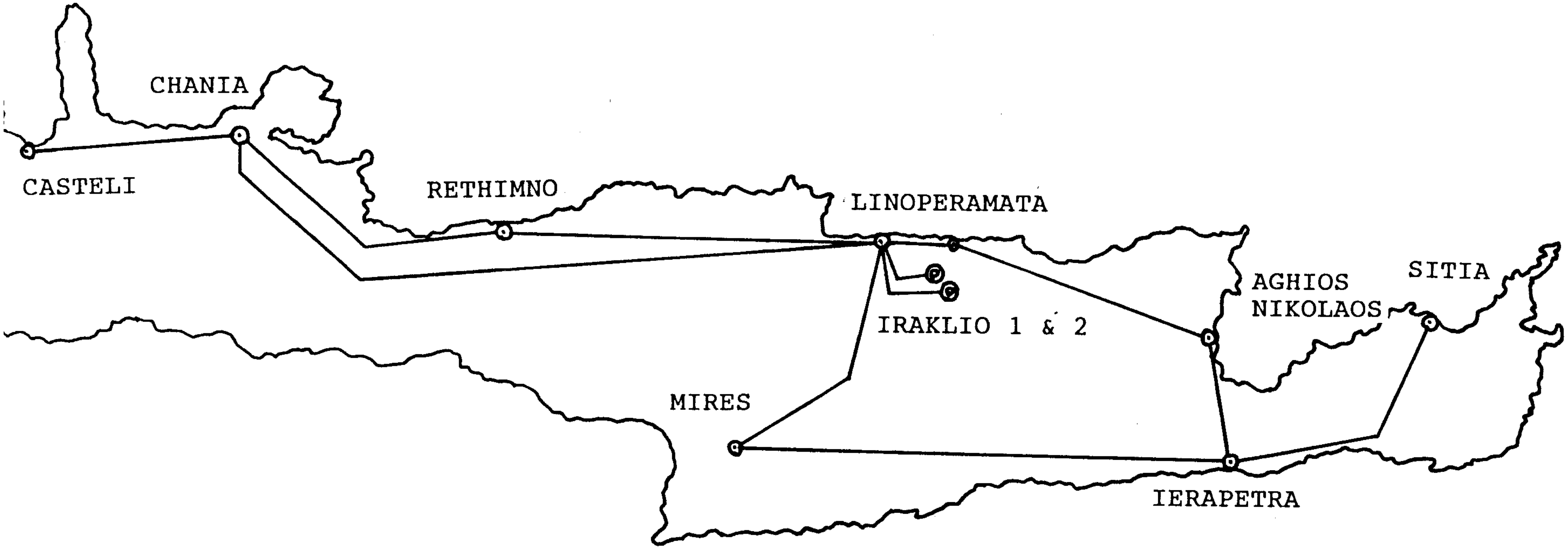

Figure 1. The island of Crete and topography of its high-voltage grid.

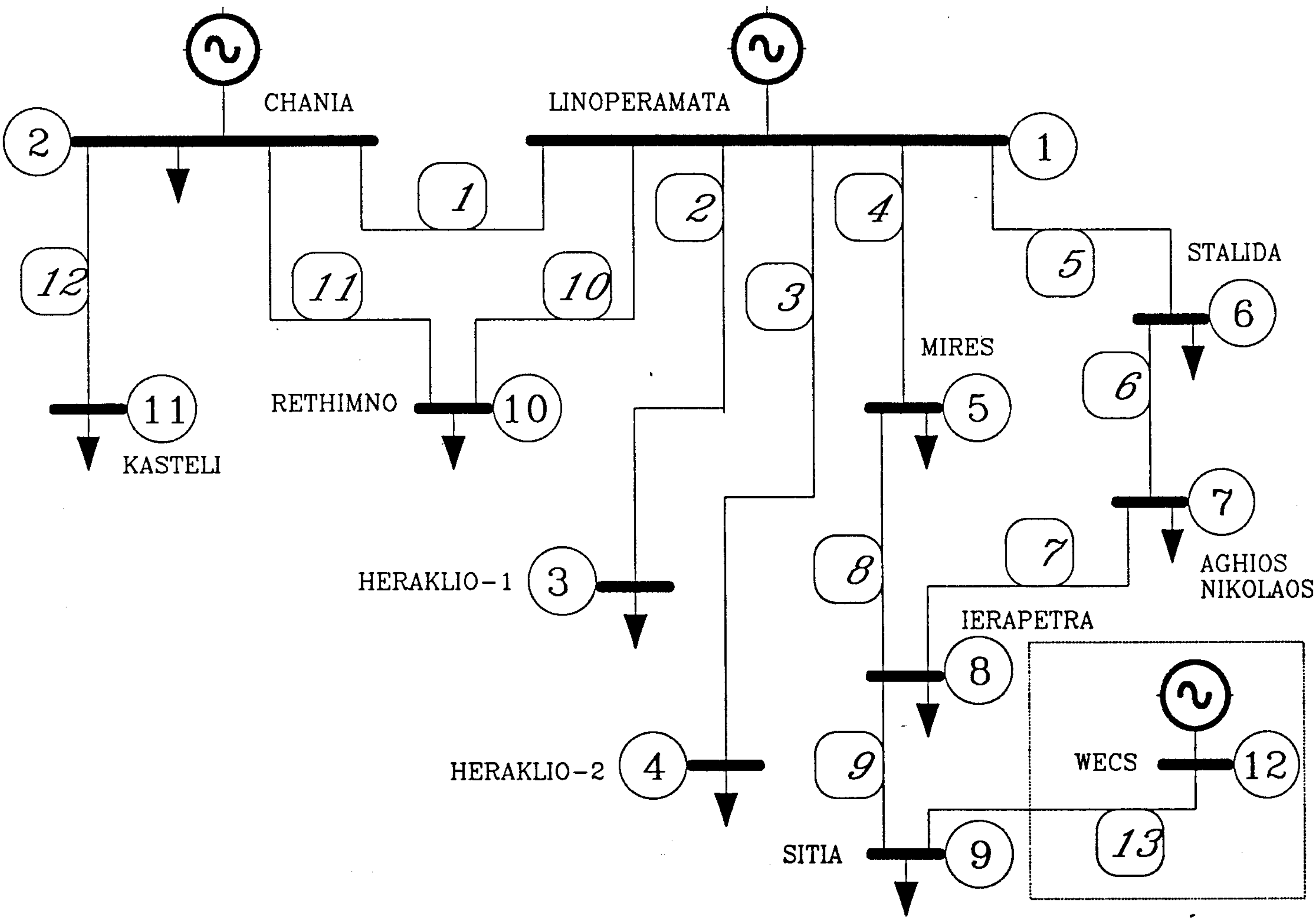

Figure 2. Schematic representation of the power system of Crete.

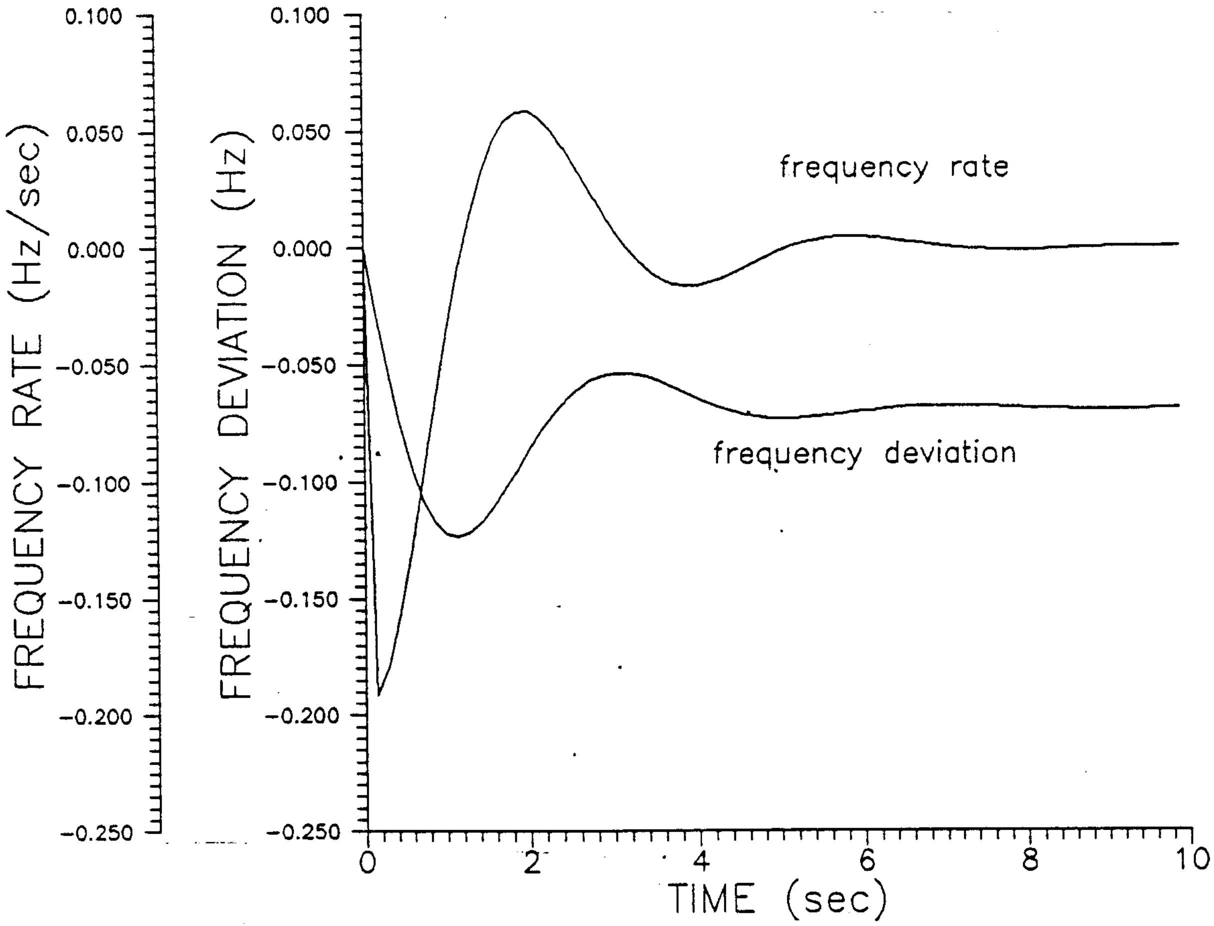

Figure 3b. Sudden rejection of the total WECS capacity under minimum loading conditions.

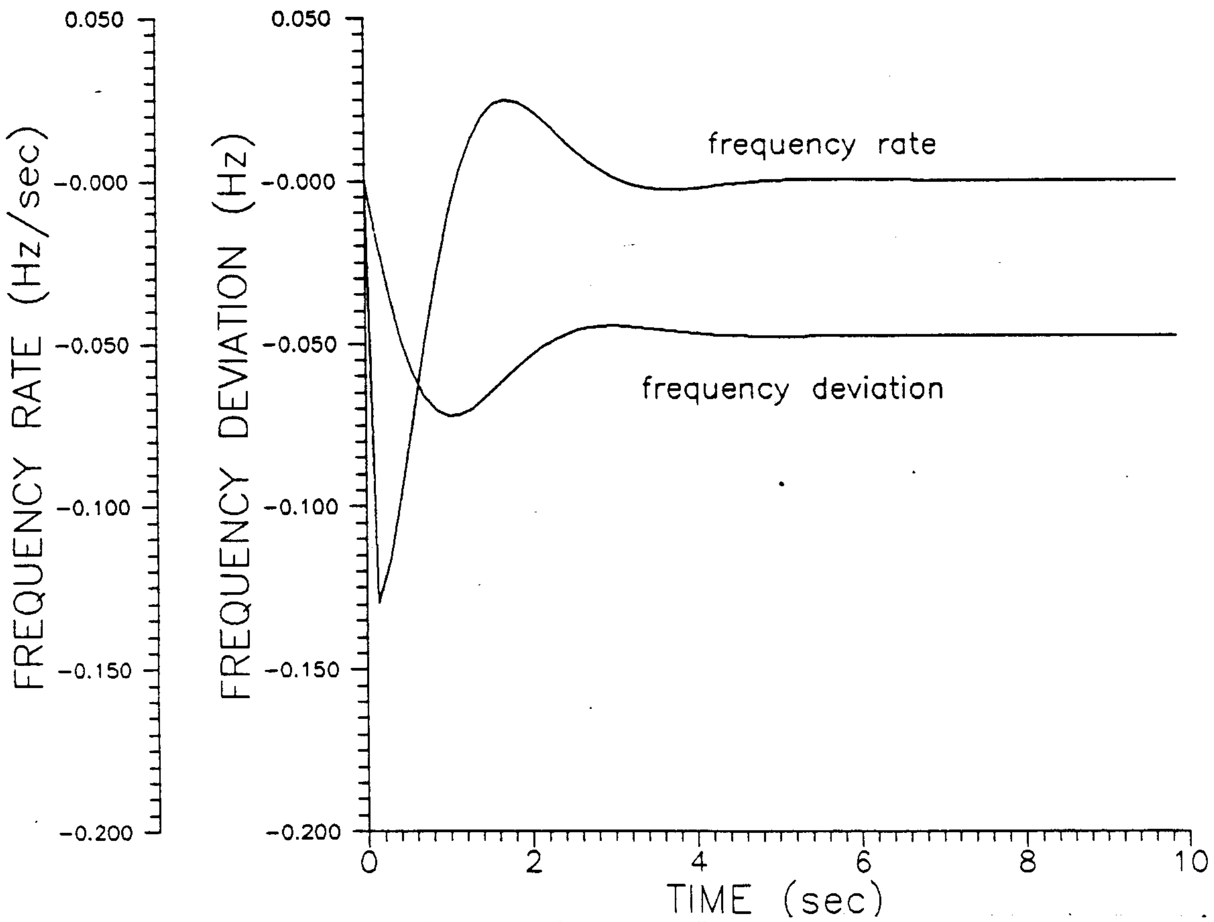

Figure 3a. Sudden rejection of the total WECS capacity under maximum loading conditions.