ISTANBUL UNIVERSITY –
JOURNAL OF ELECTRICAL & ELECTRONICS ENGINEERING

YEAR : 2010 (1153 - 1162)
VOLUME : 10
NUMBER : 1

POWER PLANTS MONITORING FOR REVERSE POWER FLOW EVALUATION

Sezai TAŞKIN

Department of Electronics and Automation, Celal Bayar University, Turgutlu-Manisa, Turkey

E-mail : sezai.taskin@cbu.edu.tr

ABSTRACT

Power plant generators are important components of an electrical energy system. They should be constantly monitored and protected in order to maintain the quality and reliability of the power supply. Otherwise, generators may occur in case of faults or incorrect operation. One of them is reverse power condition. Reverse power flow can be cause important problems if it is not considered in the protection system design.

The objective of this study is to investigate of the reverse power condition of the power plants generators. For this purpose, reverse power data are collected from a cogeneration power plant generators protection relays. The relays are able to detect disturbances and when these occurs, all digital and analogical signals are stored in its memory, including the pre-fault, fault and post-fault intervals. Hence, the reverse power data, which are collected during the transition case from abnormal condition of the generators to motoring mode, present current, voltage, active and reactive power data as well as frequency variations, are analyzed for two generators.

Keywords : *Power plants, reverse power flow, generator protection, , digital fault recorder.*

1. INTRODUCTION

Countries generate most of their electricity in large centralized facilities, such as fossil fuels, nuclear or hydropower plants. These power plants have excellent economies of scale, but usually transmit electricity long distances. Hence, small localized power sources, commonly known as “Distributed Generation”, have become a popular alternative for electric power generation [1].

When the distributed generators are operated in parallel with the utility systems, some problems occur due to interconnections such as reverse power flow. Generators are heart of power systems. Therefore, it needs the maximum protection from the occurring faults.

Power generators are important components of an electrical energy system and should be constantly monitored and protected in order to maintain the quality and reliability of the power supply. This task is performed by the protection system, the Supervisory Control and Data Acquisition (SCADA) system and also by Digital Fault Recorders (DFRs) [2].

Generators need to be protected not only from short circuits, but also from abnormal operating conditions. Examples of such abnormal conditions are over-excitation, over-voltage, and loss of field, unbalanced currents, reverse power, and abnormal frequency. When subjected to

Received Date : 12.12.2008
Accepted Date: 24.08.2009

these conditions, damage or complete failure can occur within seconds. This condition requires automatic detection and tripping [3].

The DFRs have been widely used by the utilities, providing valuable means to a deeper analysis of disturbances that commonly occur in power systems [2]. When installed in power plants, the DFRs record sampled waveforms of voltage and current signals, besides the status of relays and other digital quantities related to the generator circuit.

Concerning with protection systems, many study have been published in the literature. Moreto et al. study is focused on the development of an automated scheme to examine digital fault recorder recordings, correlating this information with the sequence of events provided by SCADA systems [2]. Other study presents a new wavelet-based negative-phase sequence (unbalanced currents) protection scheme for synchronous generators [3]. Davidson et al. show the application of a multi-agent system to the automatic fault diagnosis of a real transmission system [4]. Another study proposed an expert system that makes use of data from DFRs and sequence of events of digital protection relays to analyze the disturbance and evaluate the protection performance [5]. Styvaktakis et al. have employed a Kalman filter to separate the oscilography into pre-fault, fault and post-fault stages [6].

This work focused on the analyzing of power plants generators reverse power conditions. For this purpose, reverse power data are collected from the Manisa Organized Industrial District (MOSB) Cogeneration Power Plant generators using by protection relays. These relays are able to detect disturbances. When the disturbances occurred, all digital and analogical signals are stored in its memory. Data sampling rate for the relays are selected as 10 ms. Hence, total recording time is 7.96 s. for pre-fault, fault and post-fault data from abnormal condition of the generator.

2. POWER SYSTEM PROTECTION

The primary purpose of power system protection is to ensure safe operation of power systems. Furthermore, the task is to minimize the impact of unavoidable faults in the system [7]. In Fig. 1, general schema for protective relaying system consisting of instrument transformers, a relay, and a circuit breaker is shown [8].

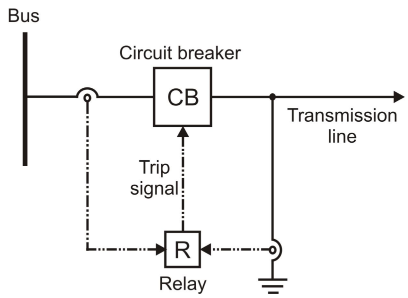


Figure 1. General protective relaying system

Most protective relays use digital processors to deploy a wide range of functions, and are programmable to allow more sophisticated criteria for initiating interrupt procedures to be applied. Modern digital relays have also started to fulfill a monitoring function since they can record the voltages and currents they measure for a period before and after any fault [9].

2.1. Reverse Power Flow Mechanism

Radial distribution networks are usually designed for unidirectional power flow, from the in feed downstream to the loads. This assumption is reflected in standard protection schemes with directional over current relays. With a generator on the distribution feeder, the load flow situation may be change [10].

The generator used is a synchronous machine which can either run as generator or motor depending upon the form of input energy. The definition of motor and generator operation relates to the sign of the average power. During the motoring action of the generator the power flows from the bus-bars to the machine. This condition is called as reverse power flow.

During the reverse power condition alternator runs as synchronous motor and the turbine acts as a load. Motoring protection is mainly for the benefit of the prime mover and load coming on the generator bus-bar while motoring reverse power protection measures the power flow from bus-bars to the generator running as a motor. The gas turbine driven generator shouldn't be permitted to operate as a motor because the gas turbine offers a load of 10 to 50% of full load during motoring. So, the reverse power protection is generally set for 10% of rated power in reverse power condition [11].

The reverse power relay is used to protect a synchronous generator, running in parallel, from motoring. Reverse power relay is similar to a watt-hour meter and provides logic action to trip when power is flowing in to the generator. The function of the reverse power relay is to prevent a reverse power condition in which power flows from the bus bar into the generator [12]. In Fig. 2, a modern programmable protection relay functions are shown [7]. Relay numbers are explained in Table 1. In this figure, number of 32 represents the reverse power sensing function.

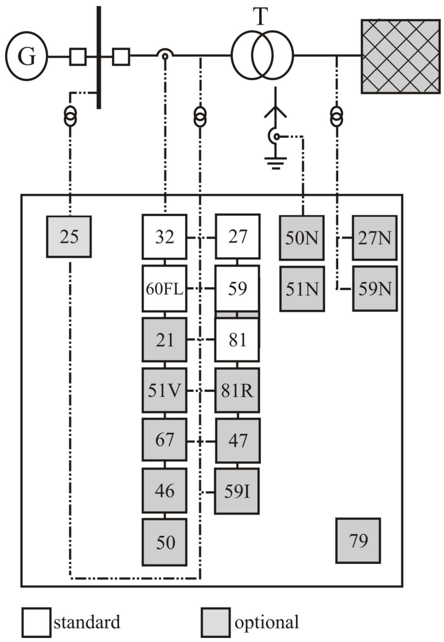


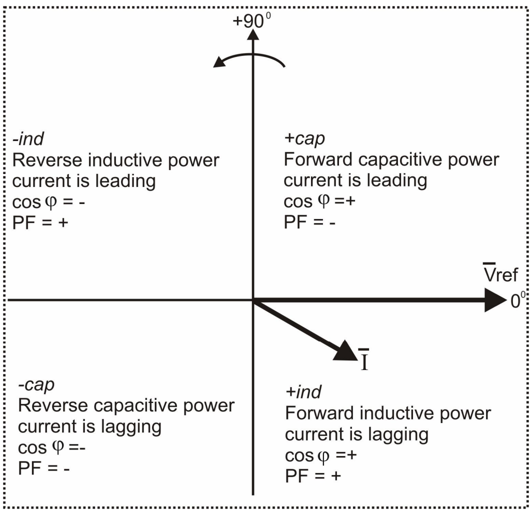
Figure 2. Typical multifunction interconnect relay

Table 1. Explanation of the relay numbers [7]

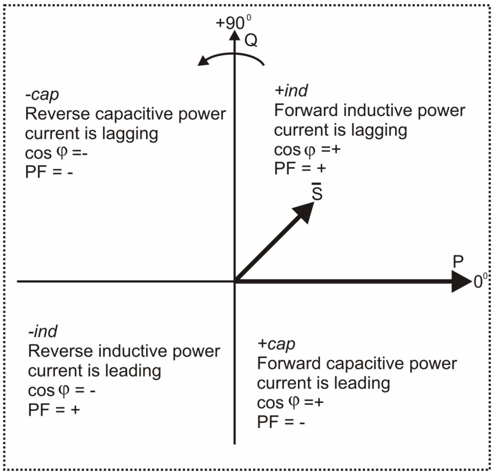
IEEE/ANSI Code	Function Name
21	distance
25	synchronizing
27	undervoltage
27N	neutral undervoltage
32	directional power *(reverse power condition)*
46	negative seq. current
47	negative seq. voltage
50	instantaneous overcurrent
50N	neutral instantaneous overcurrent
51N	neutral time overcurrent
59	overvoltage
59I	instantaneous overvoltage
59N	neutral overvoltage
60FL	voltage transformer fuse failure
67	directional overcurrent
79	reclosing
81	frequency (under and over)
81R	rate of change of frequency

2.2. Direction of Power and Current during the Reverse Power Detection

Fig. 3 (a) shows the concept of three phase current direction and sign of cos φ and power factor (PF) and (b) shows the same concepts, but on a PQ-power plane, respectively.



(a)



(b)

Figure 3. a) Quadrants of voltage/current phasor plane
b) Quadrants of power plane [13]

3. COGENERATION PLANTS

Cogeneration is the simultaneous production of electricity and heat from a single fuel source such as natural gas, biomass, biogas, coal, waste heat, or oil. A cogeneration system recovers the heat normally lost in electricity generation for use in cooling, heating, dehumidification and other processes. One of the most common cogeneration systems is gas turbine or engine with heat recovery unit. Gas turbine or engine cogeneration systems generate electricity by burning fuel (natural gas or biogas) to generate electricity and then use a heat recovery unit to capture heat from the combustion system exhaust stream. This heat is converted into useful thermal energy, usually in the form of steam or hot water [14].

3.1. Overview to the Cogeneration Power Plant

For the study, reverse power data are collected from MOSB-Energy Cogeneration Power Plant. The power plant has an 84.8 MW total power. It is established at Manisa in western of Turkey. The plant use natural gas for primary energy source. Three generators have 16.638 MW and five generators have 8.730 MW electrical outputs. The generators deliver electricity through 33 kV transformers to the local grid of the industrial park. The total steam production capacity is around 45 tones/h. Hot water is fed into the district heating system of the industrial park [15].

In Fig. 4, the cogeneration power plant block diagram is given. In this here, the heat output from gas turbine is all found in its exhaust. This is a high temperature source and it can be used to generate high temperature, high pressure steam. This steam will be generated in a waste-heat boiler attached directly to the turbine exhaust [16, 17].

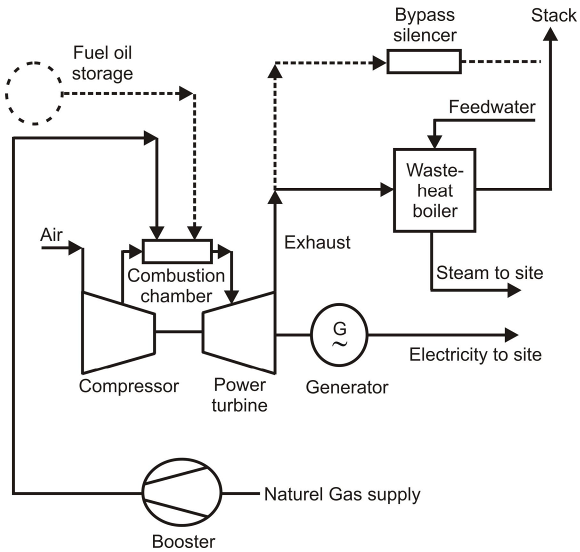


Figure 4. Block diagram of gas turbine based cogeneration power plants

4. DATA COLLECTION SYSTEM

Reverse power data are collected by using the generator protection relays. The relays are also able to detect disturbances. When these disturbances occur, all digital and analogical signals are stored in its memory, including the pre-fault, fault and post-fault intervals. Disturbance recorder sampling rate is selected as 100 S/s. Hence, total data number size is 796 S. In Fig. 5, the reverse power data measurement system is given generally.

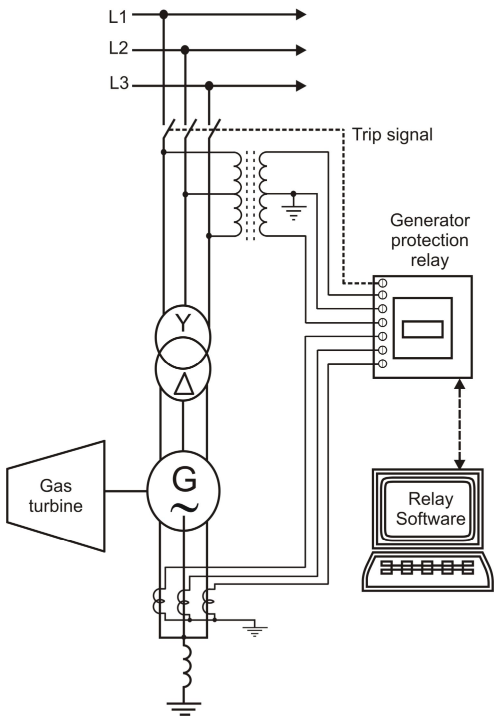


Figure 5. Reverse power data collection system

4.1. The Power Plant Generator Specifications

In Table 2, the power plant generators, which are connected to the disturbance recorder for the reverse power flow, specifications are given.

Table 2. Power Plant Generator Specifications

	Electrical Parameter	Nominal Value	
1	Generator nominal power	10670	kVA
2	Nominal shaft power (Pm)	8730	kW
3	Active Power	9030	kW
4	Reactive Power	1582	kVar
5	Power factor	0.98	
6	Setting for stage P<	-4.0	%Pm
7	Setting for stage P<<	-20	%Pm

Disturbance recorder parameters and its values for the generators are also shown in Table 3.

Table 3. Disturbance recorder parameters

	Electrical Measurement Parameter	**Value**	
1	Active Power	9030	kW
2	Reactive Power	1582	kVar
3	Apparent Power	8518	kVA
4	Power Factor	0.98	
5	Frequency	49.980	Hz
6	Phase current IL1	437	A
7	Phase current IL2	435	A
8	Phase current IL3	440	A
9	Io residual current	0.00	A
10	Io2 residual current	0.000	A
11	Line voltage U12	11590	V
12	Line voltage U23	11595	V
13	Line voltage U31	11600	V
14	Phase voltage UL1	6695	V
15	Phase voltage UL2	6700	V
16	Phase voltage UL3	6705	V
17	Residual voltage	0.0	%
18	Unbalance (I2/Igen)	0.3	%
19	Current –seq./+seq.	0.2	%

5. APPLICATION TO DATA AND RESULTS

In this study, the reverse power data, which are collected during the transition case from abnormal condition of the generators to motoring mode, present current, voltage, active and reactive power data as well as frequency variations, are analyzed in time-scale. In this sense, the time-domain variations related to the reverse power cases are shown by the following figures.

5.1. Reverse Power Data Analysis for the Generator-1

As seen in Fig. 5 the total measurement time is 7.96 second with sampling rate at 100 S/s. Here we can define four different time-regions:

a) The first one, between the 0 and 1.5 s, indicates the decreasing of the current in generator mode,
b) The second one is related to the motoring mode which is defined between the 1.5 and 3 s;

c) The third one takes place between the 3 and 4 s and it denotes the critical region of the data before the tripping signal of the protection relay,
d) And also, the last one shows the separation region of the generator from the bus bar.

According to the current signal variations, the voltage variations begins to drop to zero level at the tripping time, which is almost at 4 s. The voltage variation is also presented in Fig. 6. All three phase currents and voltage variations have same changing characteristics in disturbance recorder results. Hence, only one phase results plotted in the study.

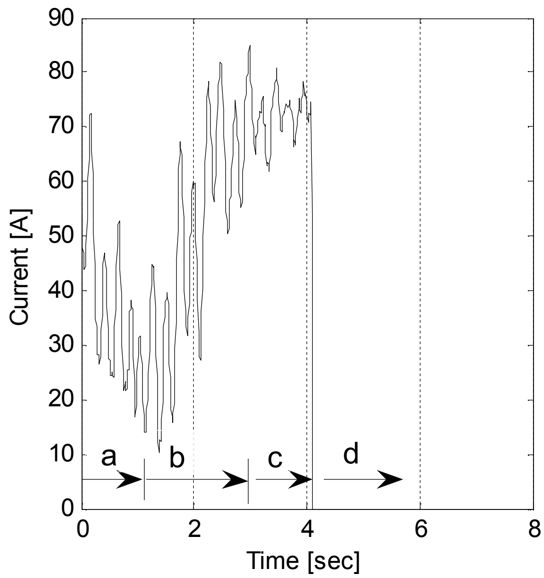


Figure 5. Current variations of the G-1

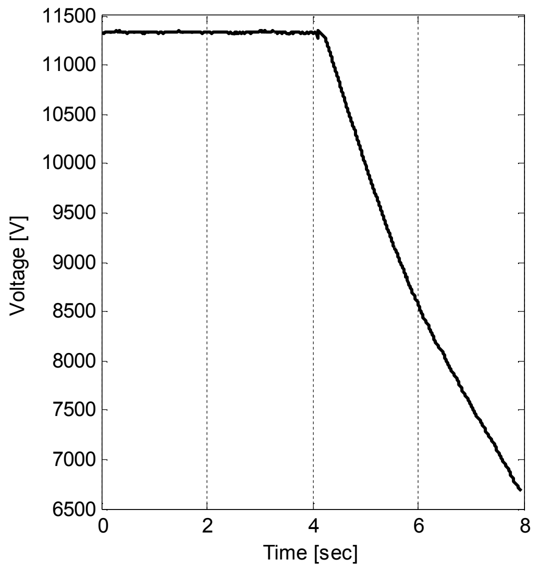


Figure 6. Voltage variations of the G-1

In terms of the active and reactive power variations during the reverse power condition of the power plant generator, the similar findings as obtained for the current signal are found. However, active power direction is depended on the power factor sign. For this reason its changing from positive side to negative side is indicated by the power factor sign. This situation can be easily observed as seen in Fig. 3 (a) and (b).

Following figures show the active and reactive power and frequency variations of the generator respectively.

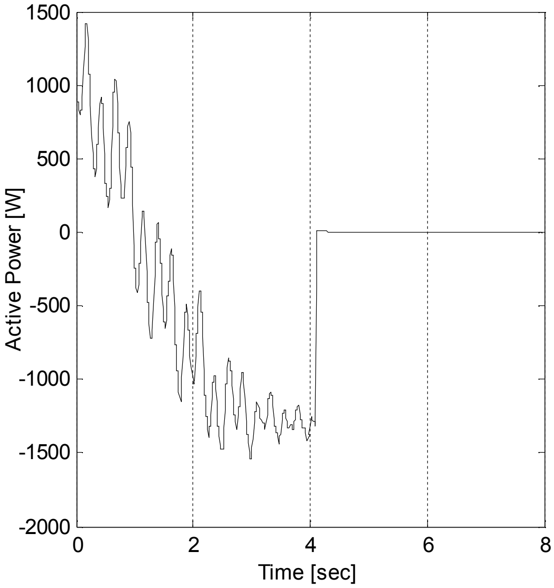


Figure 7. Active power variations of the G-1

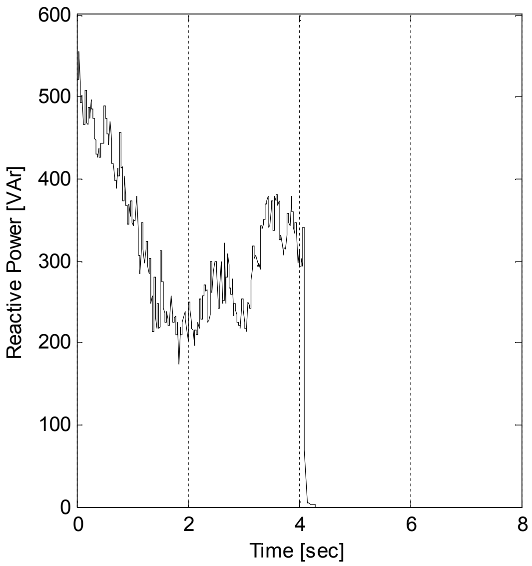


Figure 8. Reactive power variations of the G-1

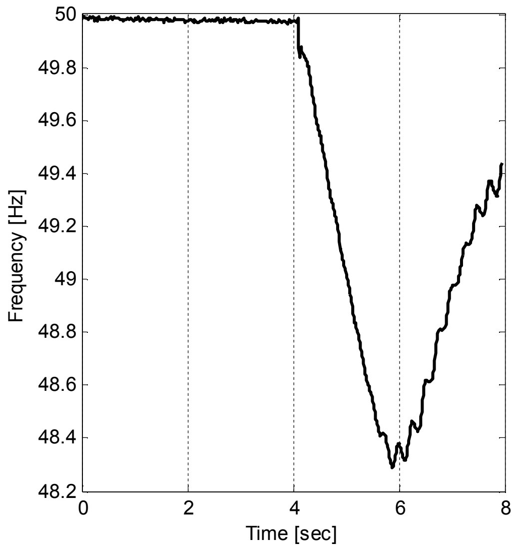


Figure 9. Frequency variations of the G-1

5.2. Reverse Power Data Analysis for the Generator-2

Following the similar steps as above, related data to the Generator-2 (G-2) can be analyzed. According to the analyzing results, Fig. 10 shows the different current characteristic from the G-1, which depends on sensing conditions of the disturbance recorder. Here, while the current of the G-2 oscillates at around 20 A up to 2nd second, after the 2nd second it shows huge changes up to 4th second and then it reaches to zero.

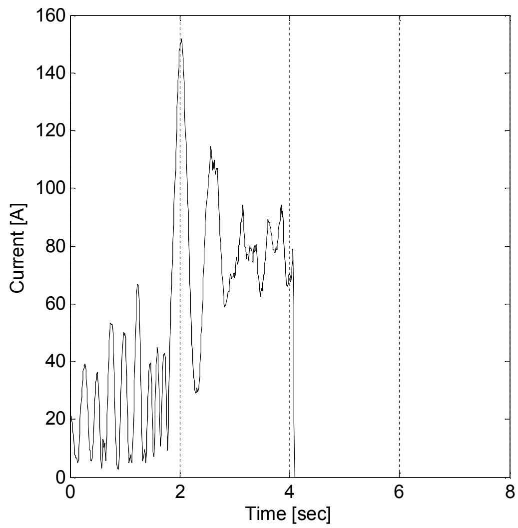


Figure 10. Current variations of the G-2.

Also, Fig.11 shows the changes in voltage and it begins to drop from the 11300 V. Hence, it reaches to zero value in a sufficient time.

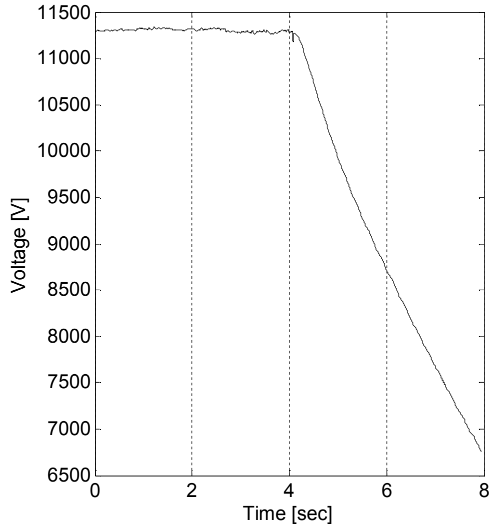


Figure 11. Voltage variations of the G2.

In terms of the Fig. 12, there is a exact suitability between the current and active power of the G-2.

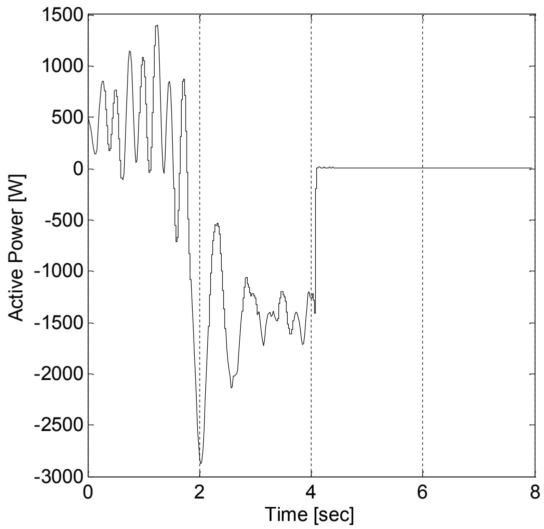


Figure 12. Active power variations of the G-2

However, Fig. 13, which indicates the reactive power variation, shows similar behavior with the current variation between the 0 and 4^{th} seconds. Namely, there is a common trend within this time interval. For this reason reactive power variation is correlated with the generator current.

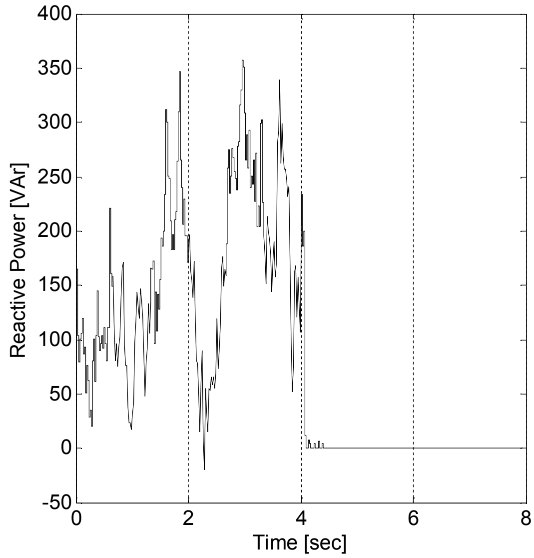


Figure 13. Reactive power variations of the G-2

As seen in Fig. 14, frequency variation begins to different operating condition after the 5^{th} second. This different operating condition can be connected with the bus-bar system.

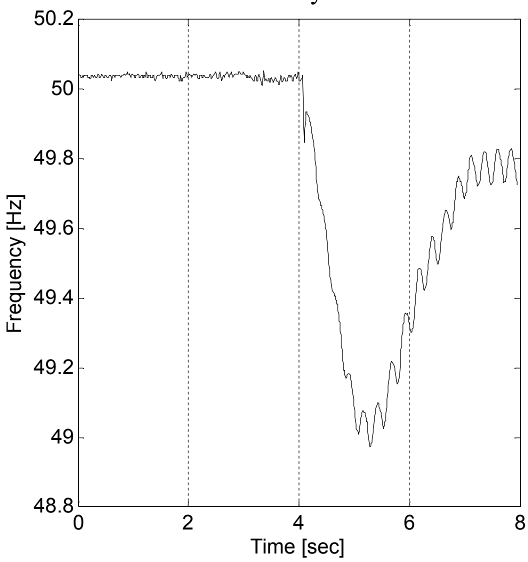


Figure 14. Frequency variations of the G-2

6. CONCLUSION

In terms of the current, active and reactive power variations the most important classification on the time can be given among the 0-1.5 s, 1.5-3 s and 3-4 s. In this manner the most common property of the reverse power event is shown by the relation, which is defined between the current and reactive power variations. Because, the reactive power variation reflects the common properties of the current variation. Namely, in terms of the time-domain characteristics the reactive power follows the current characteristics related to time. It means that there is a correlation between the current and reactive power relation.

As a future work, these collected signals can be explained in frequency domain and hence their fundamental properties can be extracted in the frequency domain and some special conditions of the reverse power phenomenon can be determined.

Acknowledgement : Author present their special thanks to the general manager and technical/engineering units of the MOSB-Energy in Turkey for the supports provided during this research.

7. REFERENCE

[1] Wrinch, M. C, *Negative Sequence Impedance Measurement for Distributed Generator Islanding Detection*, The University Of British Columbia, Ph.D Thesis, 2008.

[2] Moreto, M., G. Rolim, J., “Automated Analysis of Digital Fault Recorder Data in Power Generating Plants”, *International Journal of Innovations in Energy Systems and Power*, Vol.3, No. 2, 2008.

[3] Youssef, O.A.S., “A wavelet-based approach for protection of generators against unbalanced currents”, *Electric Power Systems Research*, Vol. 63, Issue 1, 2002.

[4] Davidson, E.M., McArthur, S.D.J., McDonald, J.R., Cumming, T., Watt, I., “Applying multi-agent system technology in practice: Automated management and analysis of SCADA and digital fault recorder data”, *IEEE Transactions on Power Systems*, Vol. 21, Issue 2, 2006.

[5] Luo, X., Kezunovic, M., “Fault analysis based on integration of digital relay and DFR data” *IEEE Power Engineering Society General Meeting*, San Francisco, USA, 2005.

[6] Styvaktakis, E. Bolen, M. H. J. Gu, I. Y. H. , “Expert system for classification and analysis of power system events”, *IEEE Power Engineering Review*, Vol. 22, Issue 2, 2002.

[7] Geidl, M., *Protection of Power Systems with Distributed Generation: State of the Art*, Swiss Federal Institute of Technology (ETH), Power Systems Laboratory Reports, July 2005.

[8] Blackburn, J.L., Domin, T.J., *Protective Relaying: Principles and Applications*, CRC Press, 2007.

[9] Tavner, P.J., Ran, L., Penman, J., *Condition Monitoring of Rotating Electrical Machines,* IET Power and Energy Series, Vol. 56, 2008.

[10] Lopes, J.A.P., “Integration of dispersed generation on distribution networks impact studies”, *IEEE Power Engineering Society*, Vol.1, p: 323-328, 2002.

[11] Rao, T.S.M, *Power System Protection Static Relays*, Tata McGraw-Hill Publishing Co. Ltd., New Delhi, India, 1981.

[12] Black & Veatch, *Power plant engineering*, Springer Science and Business Inc., 1996.

[13] *Wamp-210 generator protection relay manual*, 2007.

[14] *Combined Heat and Power: A Clean, Local Energy Solution*, Energy Matters, 2009.

[15] Wartsila Company Brochure, *Combined Heat and Power Plants*, www.wartsila.com, April 2009.

[16] Breeze, P.A, *Power generation technologies*, p: 69, Newnes Book, 2005.

[17] Grigsby, L. L., *Electric Power Generation, Transmission, and Distribution,* CRC Press; 2nd edition, 2007.

Sezai Taşkın received his B.Sc., M.Sc. and Ph.D., degrees from the Marmara University, Electrical Education Department, in 1999, 2001 and 2007 respectively. Presently, he is an assistant professor with Celal Bayar University Department of Electronics and Automation. His research interests have been focused on power system analysis, renewable energy resources, and mechatronic systems.