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The Role of FPGA in Modern Power System Protection Relaying

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ABSTRACT

Field Programmable Gate Arrays(FPGAs) have emerged as pivotal components in modern power system protection relaying due to their ability to execute concurrent sense-process-communicate operations efficiently. Relays, serving as the frontline guardians of power systems, are tasked with promptly detecting abnormal conditions and initiating corrective actions. This paper provides a comprehensive review of FPGA-based relay implementations, emphasizing their concurrent architecture and communication capabilities. Finally, the paper discusses the future prospects of FPGA technology in advancing modern power system protection schemes.

Index Terms: Digital Relays, FPGA Relays, Multifunction Relays, Fast Fourier Transform, Power Protection, Relay Communication

INTRODUCTION

Relays play a crucial role in safeguarding power systems by swiftly detecting and responding to abnormal conditions, ensuring the system's stability and integrity. The ideal relay response is characterized by being automatic, accurate and quick, akin to the functions of the human nervous system. Just as the human brain orchestrates actions, relays issue commands to circuit breaker- the muscular component of the power system, prompting corrective measures to isolate faulty elements and restore normalcy.

Relays have evolved from expensive electromagnetic relays to relatively cheaper and efficient solid state relays to modern and advanced digital relays which are economical, reliable and robust and are easily adaptable to changing physical conditions [1-5]. Over time, relay technology has undergone significant advancements. Initially, electromagnetic relays were predominant, followed by the introduction of solid-state relays, which offered improved efficiency and cost-effectiveness. However, these relays relied on dedicated hardware, leading to the emergence of microprocessor and microcontroller based relays. These relays provided greater flexibility and programmability; they exhibited slower response times due to their sequential processing nature. In contrast, FPGA based relays represent a significant advancement in power system protection. Leveraging concurrent architecture, FPGA based relays offer superior speed and efficiency compared to their microprocessor and microcontroller counterparts. This paper explores various pipelined architecture-based relays, such as Overcurrent, Distance, Voltage, Frequency and Differential relays implemented on FPGA platforms. These relays boast communication capabilities and multifunctionality, enhancing their adaptability to diverse protection scenarios.

Lastly, the paper examines the future prospects of FPGA technology in advancing power system protection, emphasing its potential to address evolving challenges and requirements in an increasingly dynamic energy landscape. Overall, FPGA signify a paradigm shift towards agile, reliable and adaptable protection solutions, heralding a new era in power system resilience and efficiency.

OVERCURRENT RELAY

An overcurrent relay is a protective device used in electrical power systems to detect and respond to excessive currents flowing in a circuit. Its primary function is to trip or open the circuit breaker when the current exceeds a predetermined threshold, thereby preventing damage to equipment and ensuring the safety of the system. Microprocessor based overcurrent relay is implemented in [6-12] but these relays are sequential in nature. Ref [13] presented FPGA based overcurrent relay with help of comparator, counter and look up tables. Simulation results are presented on Application Specific Integrated Circuit (ASIC) based design. The relay is implemented without any harmonic filtering. Ref [14] demonstrated Altera's Cylone based Overcurrent Relay. The relay is implemented on FPGA based System on Programmable Chip (SOPC) design. Lookup table based overcurrent Relay is presented in [15]. The relay shows Inverse Time Current Characteristics [16]. These FPGA based relays not reported relay communication and harmonic filtering. Ref. [17] implemented concurrent sense-process-communicate cycle based FPGA relay. The concurrent sense, process and communicate module is implemented. The pipeline control module is taking care for generation of clocks and exchange signals between module. Fast Fourier Transform (FFT) filtering is done for extraction of fundamental frequency component so that false tripping is avoided. The relay is capable of removing the transient faults as FFT filtering is done in the design. Relay is implemented on XILINX Virtex-II Pro XC2VP30 FF896-7CFPGA chip and tested on HONALEC 360 km 400 kV Transmission Line Hardware Simulator comprising of 12 sections of 30 km each. Different test results by creating various faults are presented in the paper. The test results are communicated to hyperterminal with Universal Asynchronous Receiver Transmistter (UART) interface i.e. further converted into IP using MOXA Nport 5110 serial device server for networked communication in TCP/IP.

Overall, FPGA-based overcurrent relays represent a significant advancement in protective relay technology, offering enhanced functionality and performance compared to traditional approaches.

FREQUENCY RELAY

A frequency relay, also known as an underfrequency relay or overfrequency relay, is an essential component in electrical protection systems. Its primary function is to monitor the frequency of an electrical power system and act upon deviations from the nominal frequency. A detailed literature review of solid state and microprocessor based frequency relay is presented in [18]. Microprocessor based frequency relay is preferred over solid state device based frequency relay due to flexibility and programming approach. Ref. [18] presents multifunction frequency relay implemented on GENESYS XILINX VIRTEX-5 XC5VLX50T FPGA board. Both underfrequency and overfrequency relay is implemented in the same FPGA board. Test results for both the Constant Frequency Mode (CFM) and Variable Frequency Mode (VFM) is presented in the paper. FPGA based multifunction relay is implemented with concurrent sense-process-communicate modules. Relay programming is done on Very high speed integrated circuit Hardware Description Language (VHDL) with help of Intellectual Properties (IP) cores. Test results are communicated to hyperterminal with help of serial interface i.e. further converted to into IP with help of MOXA Nport 5110 serial interface for working in network communication in TCP/IP. Relay is tested on HONALEC 360 km 400 kV Transmission Line Hardware Simulator.

VOLTAGE RELAY

A voltage relay is an electrical device designed to monitor voltage levels in a circuit and initiate a response when these levels deviate from predetermined thresholds. It is commonly used in various applications to protect electrical equipment, prevent damage due to voltage fluctuations, and ensure system stability. Ref [19] presents detailed literature review of Electromechanical and Microprocessor based Voltage relay. Programming based voltage relay has flexibility to operate different functionality of the relay by changing the program. A pipelined architecture based multifunction voltage relay is demonstrated in [19]. Relay is implemented on Genesys Xilinx Virtex-5XC5VLX50T FF1136 FPGA board. Relay is comprises of ADC module, counter, peak detector, voltage relay measurement module and float to ASCII module. A pipelined architecture based sense, process and communicate module implemented with help of VHDL programming. Test results are communicated to hyperterminal i.e. further conveted to TCP/IP for networking environment. Overvolatge and undervoltage relay is implemented on same FPGA board. Clock divider circuit is used to generate different baud rates.

In summary, voltage relays play a critical role in safeguarding electrical systems by continuously monitoring voltage levels and responding to deviations to prevent equipment damage and ensure system reliability.

DIFFERENTIAL RELAY

Differential relays are essential components in electrical protection systems, primarily used to detect and respond to internal faults within power system equipment. Microprocessor/microcontroller based differential relays are presented in [20-21]. These relays are slow due to sequential approach. FPGA based differential relays are presented in [22-24]. Simulation based results are presented in the paper. Ref [25] presents concurrent architecture based differential relay on FPGA. Dual channel Analog 7476 A ADC is used for collecting voltages from both of its channel. A pipelined sense-process-communicate module are implemented on FPGA. Line 1, Line 2 and difference of voltage communicated to the hyperterminal with UART interface. Test results are further converted to TCP/IP with the help of WIZNET WIZ110SR serial to ethernet adapter. Differential relay programming is done on VHDL. Differential Relay is implemented on Virtex 5 XC5VLX50TFFG1136C FPGA board. Different test results and device utilization summary is reported in the paper.

CONCLUSION

This paper emphases on different concurrent architecture based FPGA relays. FPGA-based relays are highlighted for their reconfigurable and concurrent architecture, which enables them to process tasks in parallel. This architecture allows for faster operation compared to traditional Microprocessor/Microcontroller based relays. The sense and communicate module of these relays operates at some kHz frequency, while the process module operates at MHz frequency. This separation allows for efficient handling of emergency conditions and additional functionality within the process module. Phasor Measurement Units(PMUs), Digital Energy Meter , Data logging and more advanced feature of the Modern Power System Protection Schemes can be incorporated in the design. These relays can communicate with each other, enabling collaborative decision-making and enhancing the overall reliability of the power system. The relays can leverage artificial intelligence for decision-making by communicating data to other networks. This capability enables intelligent load shedding and relay trip decisions based on real-time data analysis. The relays are configured with GPS modules, allowing them to communicate UTC position and other relevant parameters. This feature enhances situational awareness and enables precise location-based actions or decisions.

REFERENCES

[1]. L.P.Singh, Digital Protection Protective Relaying from Electromechanical to Microprocessor, Second Edition, New Age International (P) Limited, 1997.

[2]. S. H.Horowitz and A.G.Phadke, Power System Relaying, Third Edition, John Wiley and Sons Inc., 2008.

[3]. B. Ram and D.N.Vishwakarma, Power System Protection and Switchgear, Tata McGraw Hill, 2007.

[4]. B.Ravindranath and M.Chander, Power System Protection and Switchgear, First Edition, New Age International (P) Limited, 2005.

[5]. A.R.vanC.Warrington, Protective Relays Their Theory and Practice, vol.2, John Wiley and Sons Inc., 1969.

[6]. Karl Zimmerman, "Microprocessor-Based Distribution Relay Applications," Schweitzer Engineering Laboratories Inc.

[7]. T.S.Sindhu,M.S.Sachdev and H.C.Wood, "Design of a Microprocessor based Overcurrent Relay", IEEE Conf. on Computer,Power and Communications system in Rulal Environment, pp-41-46, May 1991.

[8]. Mahmoud A.Manzoul, "Interrupt-Driven Microprocessor-Based Overcurrent Relay", IEEE Transactions on Industrial Electronics, vol.38, no.1, pp 8-9, Feb.1991.

[9]. Edmund O. Schweitzer, Ill and Mark W. Feltis, "Advances in Microprocessor-Based Distribution Relays", Schweitzer Engineering Laboratories Inc.

[10]. M.A. Manzoul, "Multiple Overcurrent Relays using a Single Microprocessor", IEEE Transaction on Industrial Electronics, vol.37, no.4, pp.307-309, Aug. 1990.

[11]. Arturo Conde and Ernesto Vázquez, "Operation Logic Proposed for Time Overcurrent Relays", IEEE Transactions on Power Delivery, vol.22, no.4, pp.2034-2039 ,Oct. 2007.

[12]. Jawad Faiz, Saeed Lotfi-fard, and Saied Haidarian Shahri, "Prony-Based Optimal Bayes Fault Classification of Overcurrent Protection", IEEE Transactions on Power Delivery, vol.22, no.3, pp.1326-1334, July 2007.

[13]. M. A. Manzoul, "Overcurrent Relay on FPGA", Microelectronics Reliability, vo1.35, no.7, pp.1017-1022, 1995.

[14]. Vishal Kumar, Sanjay Prabhu, Indra Gupta and H. O. Gupta, "SOPC Design for Implementation of Over-current Relay," Proceeding of IEEE Power India Conference, New Delhi, April,2006.

[15]. S. Ahuja,L. Kothari, D. .N. Vishwakarma and S. K. Balasubramanian, "Field Programmable Gate Arrays Based Overcurrent Relays," Elecric Power Component and Systems,vo1.32, pp.247-255, 2004

[16]. IEEE Standard Inverse-Time Characteristic Equations for Overcurrent Relays: IEEE Transactions on Power Delivery, vol. 14, no.3.pp. 868-872, July 1999.

[17]. V. Maheshwari, D. B. Das and A. K. Saxena, "FPGA Based Digital Overcurrent Relay with Concurrent Sense-Process-Communicate Cycles," International Journal Electrical Power and Energy Systems. No. 55, pp. 66-73, Feb. 2014.

[18]. Varun Maheshwari, Akanksha Jain, Rekha Rawat, Bhagwan Das Devulapalli and A.K.Saxena, Concurrent Architecture Based Frequency Relay on FPGA, Springer Journal of The Institution of Engineers (India): Series B: 2021

[19]. Surbhi Varshney, Swati Jain ,Sugandha Gupta ,Sakshi, Varun Maheshwari, Design and Development of Multifunction Voltage Relay on FPGA, IEEE 2nd International Conference on Telecommunication and Networking, TEL-NET 2017 , August 2017

[20]. S.R. Kolla, D.V. Gedeon "Microprocessor-based protection scheme for power transformers", Electrical Electronics Insulation Conference and Electrical Manufacturing & Coil Winding Conference, 1995

[21]. Madhura S. Deshmukh, V.T. Barhate, "Microcontroller based differential Relay using Fuzzy Logic for Transformer Protection",2017 Intenational Conference on Intelligent Computing and Control Systems (ICICCS).

[22]. Khaled Shehata, Ahmed Bahaa, Atalla Hashad, " Design and Implementation of an FPGA based Protection Relay", 21st National Radio Science Conference (NRSC2004), (NTI) March 16-18,2004

[23]. Khaled Snehata,Ahmed Bahaa, Karim Morad and Ahmed Sharaf, " Design and Implementation of FPGA based and Microcontroller based current Relay",The 16th International IEEE conference on

[24]. Microelectronics, 2004 ICM 2004.

[25]. Piyush Gupta, Mayank Khandelwal, Rishi Sharma, Manish K. Singh, Naveen P. Reddy, "Differential Protection of Transformer Using FPGA", Internatinal conference on smart electri grid (ISEG), 2014.

[26]. Vandana Singh, Reetu and Varun Maheshwari, Design and Development of Concurrent Architecture based Differential Protective Relay on FPGA, IEEE International Conference on Reliability, Infocom Technologies and Optimization (Trends and Future Directions) ICRITO, Sept. 2020