Application Report
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A Numerical Protection Relay Solution

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ABSTRACT

Numerical Protection Relays (NPRs) are critical elements in any power distribution network. Generally, there are several different types of NPRs. Each type, however, shares a similar architecture, thus enabling designers to build an entire system solution that is based on a relatively small number of flexible components. This application note demonstrates how an NPR can be implemented using TI's extensive portfolio of semiconductor devices.

Contents

1 Introduction 1
2 Speed Requirements 2
3 Accuracy Requirements 3
4 Simultaneous Sampling Requirements 4
5 Component Selection 4
6 Conclusion 6
7 References 7

List of Figures

1 Typical Substation in Electrical Energy Distribution Network 2
2 Example IDMTL Curve: Long-Time, Extremely Inverse Delay 3
3 Simultaneous Sampling Requirement of Two Input Signals in an NPR 4
4 Typical Multi-Channel Overcurrent Protection Relay 4
5 Proposed NPR Solution 6

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1 Introduction

Electrical energy generated by various electrical power stations is gathered by a central electrical grid and then redistributed to various users based on real-time supply and demand characteristics. Have you ever wondered what would happen when one or more of these power stations stopped producing electrical energy, or when some of the loads suddenly demanded excessive power from the grid? As a result of the high energy levels involved (powers measuring in MW), this imbalance generated by such sudden events could lead to catastrophic failures.

Some of these situations are unavoidable and beyond human control. Consequently, the central electrical grid must run a real-time algorithm to detect such fault conditions and react quickly in order to minimize adverse impact. This monitoring function is typically managed by *make-or-break* contacts called switch-gears or relays. These relays are, in turn, controlled by a smart controlling unit that continually monitors the grid parameters (such as voltages, currents, temperature, and so forth) and switches the appropriate relays in case fault conditions occur. Most of the data processing happens in the digital domain; thus, these relays are often called *Numerical Protection Relays*, or NPRs.

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Let us first review where these NPRs are used and the specifications governing the design of these components. Figure 1 shows a typical substation in an electrical distribution system.

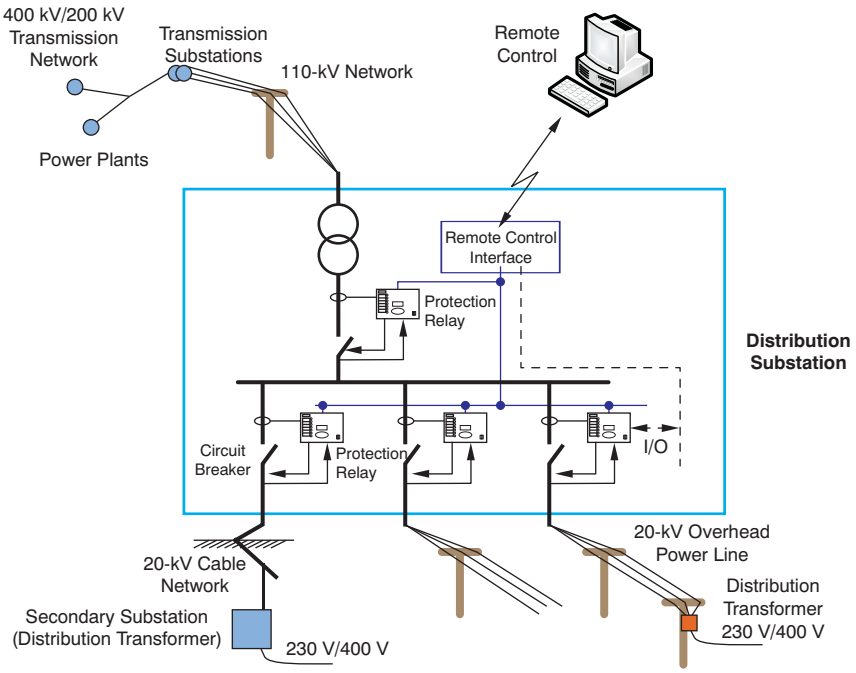

Figure 1. Typical Substation in Electrical Energy Distribution Network

2 Speed Requirements

Based on the end application and respective user geography, there are various standards such as ANSI C37.90, IEC255-4, IEC60255-3, IAC, etc. that govern the response time of the relay to the fault conditions that may occur. These response characteristics are generally represented by performance graphs called *Inverse Definite Minimum Time Lag* (IDMTL) curves. IDMTL is the measure of an NPR response time to the amount of fault/error.

Figure 2 illustrates one example IDMTL curve. The associated formula is given in Equation 1.

$$t_{RESPONSE} = DMF \bullet \left(\frac{A}{\left(\frac{I_{Measured}}{I_{Set}} \right)^{C} - 1} + B \right) \quad (1)$$

Where:

- $t_{RESPONSE}$ = Response time
- DMF = Delay Multiplier Factor
- $I_{Measured}$ = Measured current
- I_{Set} = Set current
- A, B, C = IDMTL Parameters

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Delay Type		Parameter		
		A	B	C
LTI	Long-time inverse	0.086	0.185	0.02
LTVI	Long-time very inverse	28.55	0.712	2
LTEI	Long-time extremely inverse	64.07	0.250	2
MI	Moderately inverse	0.0515	0.1140	0.02
VI	Very inverse	19.61	0.491	2
EI	Extremely inverse	28.2	0.1217	2
STI	Short-time inverse	0.16758	0.11858	0.02
STEI	Short-time extremely inverse	1.281	0.005	2

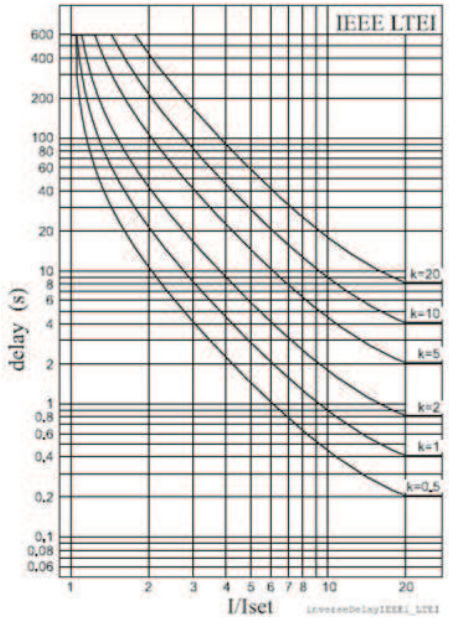

Figure 2. Example IDMTL Curve: Long-Time, Extremely Inverse Delay

From the equation given in Equation 1, it is clear that any NPR which can support a lower Delay Multiplication Factor (DMF) for a given curve will have a faster response time to the fault signal, and thus will achieve a higher product rating. In order to obtain this lower DMF and correlating faster response time, all components in the control loop must be as fast as possible without compromising accuracy.

3 Accuracy Requirements

In an NPR, the dynamic range of the input signal is often very high. For example, a typical overcurrent protection relay will be expected to monitor currents starting from few amperes (A) all the way up to its trip point setting, which could be in kilo-amperes (kA). It is also expected that the relay maintain its measurement accuracy across the entire input range. Depending on the critical nature of the application, this accuracy requirement can be anywhere from 1% to 0.05%; generally, however, the higher the accuracy, the better the relay. To achieve higher accuracy, then, the analog front end (AFE) of the system should have high resolution (~10-bit for 1%, ~16-bit for 0.05%), high linearity, high stability, and low noise, even at higher sampling speeds.

Successive-approximation register analog-to-digital converters (SAR ADCs) offer zero latency and higher linearity at higher sampling rates, compared to delta-sigma ($\Delta\Sigma$) ADCs, and are therefore preferred in this type of application. Low-noise, low-drift op amps are used in the input stage to limit noise and drift-related errors.

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4 Simultaneous Sampling Requirements

In most NPRs, the phase relationship between the signals captured from different channels is as important as the value of the signal. For example, if voltage and current from the same source are measured, and if a user wishes to calculate parameters such as active power, reactive power, power factor, impedance, or harmonics, then the phase relation between these two signals is required. This condition means that the value of both the input signals at any particular instant of time must be known. Therefore, a simultaneous sampling ADC is required in these applications. An example of such a system is shown in Figure 3.

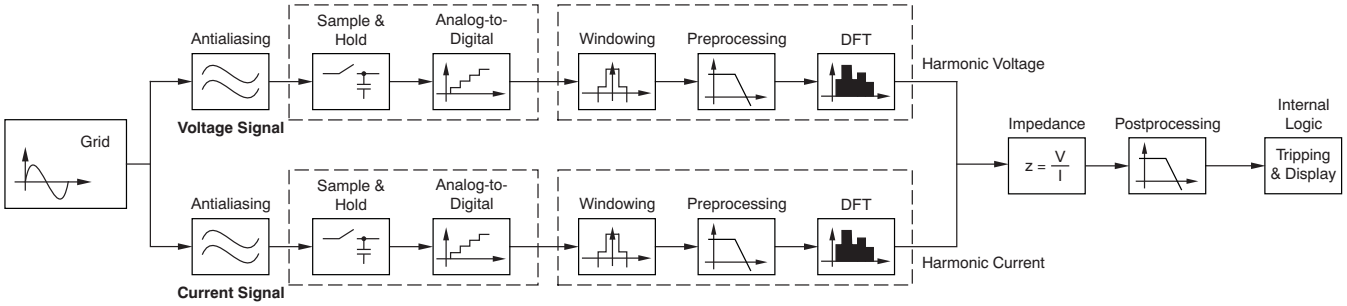

Figure 3. Simultaneous Sampling Requirement of Two Input Signals in an NPR

5 Component Selection

An NPR must be fast and accurate. From the perspective of electronics design, this requirement translates to a very high-performance AFE backed up by fast, feature-rich, digital back-end processing. In this section, we will try to determine the exact system requirements from the individual blocks.

Based on the respective responses to certain types of fault conditions, NPRs are generally classified as *Overcurrent Protection Relays*, *Overvoltage Protection Relays*, *Earth Fault Protection Relays*, *Feeder Protection Relays*, or *Distant Protection Relays*, as well as other types. It is important to understand that these different types of relays actually have very similar hardware configurations. The differentiation between the various types is based on the firmware programming. For illustration purposes, let us take an example of an Overcurrent Protection Relay.

Figure 4 shows a block diagram of a typical Overcurrent Protection Relay.

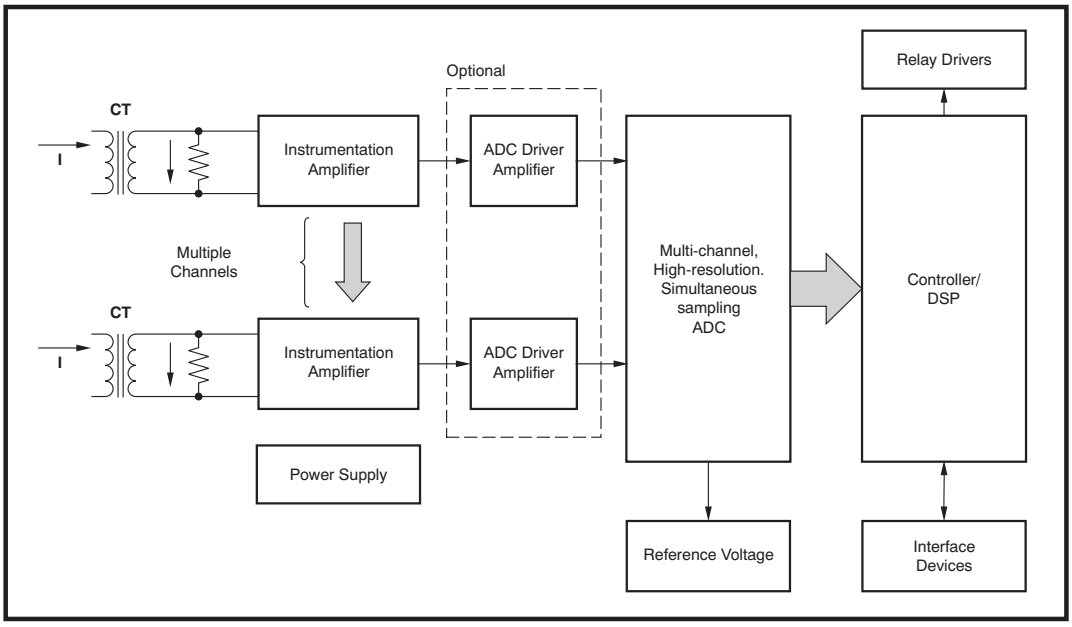

Figure 4. Typical Multi-Channel Overcurrent Protection Relay

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5.1 Amplifiers

A current transformer (CT) is generally used to sense the current in the grid. This sensed current is then converted to a differential voltage signal using the load resistor. It is preferable to use the smallest possible load resistor on the secondary side of the CT in order to reduce the reflected load seen on its primary side. Consequently, the voltage signal on the secondary side will often be as low as a few millivolts, but it can be riding on a much higher common-mode voltage. Therefore, the component used to amplify this signal should be able to provide high gain, but should also support high common-mode voltages with high CMRR. Texas Instruments' INA128 is ideal for this application.

One INA128 will be required for every CT in the system.

Based on the ADC used in the application, an extra amplifier stage may be required between the output of the instrumentation amplifier and the data converter in order to meet the settling time parameter of the ADC. This amplifier should have sufficient bandwidth, low drift, and low-noise performance. In order to maximize the usable range of the converter, this amplifier should be able to support the necessary output voltage range. Texas Instruments' OPAx277 series is very well suited for this type of application.

5.2 ADCs

The various measurements discussed earlier with the desired accuracy and speed can be summarized in this way:

- Multi-channel, simultaneous sampling ADCs are preferred in NPRs
- Faster ADCs will allow averaging of the output codes to improve overall noise performance
- A higher resolution ADC is preferred so that quantization errors are minimal. (Typically, 12- to 16-bit ADCs are used in NPRs.)
- ADCs that support a high input range are preferred. This parameter helps to increase the dynamic range of the input signal, thereby improving the signal-to-noise ratio (SNR).

Based on these requirements, Texas Instruments' ADS8556, ADS8557, and ADS8558 family is best suited for this application.

5.3 Reference

The noise performance of the data converter can be only as good as its input voltage and its reference voltage. Thus, the reference voltage used by the ADC should be accurate and stable across temperature. Texas Instruments' ADS855x ADCs have an on-chip reference voltage generator. The output of this reference can be trimmed around the center value, according to the system requirements. Once set, the reference voltage does not drift more than ±10ppm/°C across the complete temperature range. Generally, this degree of drift is sufficient in most applications. If higher stability is desired, the ADC can be used in external reference mode and Texas Instruments' REF5025 series of low-noise, very low-drift (3ppm/°C max), precision voltage references should be used to provide this reference voltage. Note that no external reference buffer is required while using the REF50xx.

5.4 Processor

As seen in the previous example (refer to Figure 3), in order to calculate various parameters such as active power, impedance, harmonics, and so forth, an FFT calculation is required based on the captured data. Consequently, a DSP engine is preferred in these types of applications. In particular, floating-point DSPs have a distinct performance advantage over fixed-point DSPs in certain applications.

In addition to the required processing power, various timers and connectivity functions in the controller are essential in order to actuate the relays and to communicate with other units.

Because this application calls for DSP-like processing and microcontroller-like peripherals, Texas Instruments' C2000™ family of Digital Signal Controllers is ideal for these applications.

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5.5 Interface and Isolation Circuits

NPRs use RS-232 and/or RS-485 and/or Ethernet protocol to communicate system status to the central command unit. It is always desirable to isolate individual modules in the network to avoid simultaneous failures. Therefore, isolation is required in both the power supply as well as communication channels. TI's isolation products such as the ISO7721 or ISO3082 are ideally suited for this application.

6 Conclusion

Numerical Protection Relays are critical elements in any power distribution subsystem. In order to avoid catastrophic failures, these relays should employ high-speed and high-accuracy electronics. A comprehensive hardware solution has been proposed (as shown in Figure 5) by using Texas Instruments' vast portfolio of analog solutions and embedded microcontrollers.

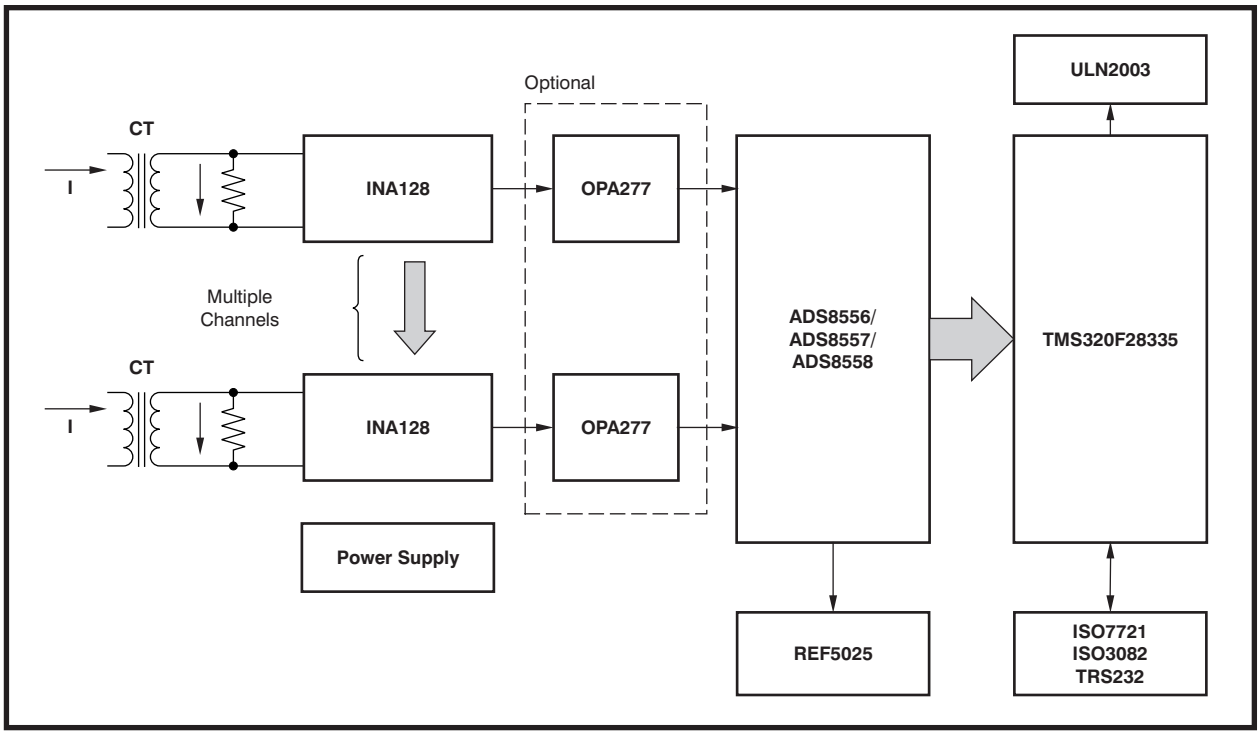

Figure 5. Proposed NPR Solution

6.1 Recommended Devices

Table 1 lists the recommended devices used in this proposed solution. All documents are available for download at www.ti.com.

Table 1. Recommended Devices

Device	Device Data Sheet
INA128	*INA12x Precision, Low-Power Instrumentation Amplifiers*
OPAx227	*OPAx22x High Precision, Low Noise Operational Amplifiers*
ADS855x	*ADS855x 16-, 14-, 12-Bit, Six-Channel, Simultaneous Sampling Analog-to-Digital Converters*
REF50xx	*REF50xx Low-Noise, Very Low Drift, Precision Voltage Reference*
TMS320F28335	*TMS320F2833x, TMS320F2823x Digital Signal Controllers (DSCs)*
ISO7721	*ISO772x High-Speed, Robust EMC Reinforced Dual-Channel Digital Isolators*
ISO3082	*ISO308x Isolated 5-V Full- and Half-Duplex RS-485 Transceivers*

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7 References

1. Power System Testing Solutions: www.omicron.at

Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Original (September 2010) to A Revision	Page
• Changed all references of the ISO7221 device to the newer ISO7721 device family throughout the document	6

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