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Universal Protection and Control Applied to a 3-Breaker Transfer Scheme

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Abstract: A new modular hardware and software based protection and control system has been developed to be more flexible and economical than conventional relay platforms for the development of custom protection and control schemes. The system includes a computer aided engineering (CAE) package to permits rapid customization of the scheme's logic and protective elements. An imbedded virtual test system allows for rapid debugging and testing. To demonstrate the system, a 3-breaker transfer scheme was developed to replace an older, existing transfer scheme based on discrete protective and logic device. This scheme integrates the transfer logic and the protective relaying functions in to one microprocessor based device.

Keywords: relay, transfer scheme, protection, control

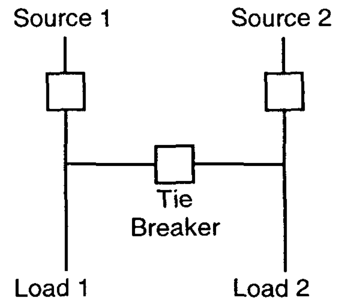
I. Introduction

This paper describes a utility's real life example of how a modular hardware and software based platform was used to rapidly implement a custom protection and control scheme integrated in to a single device. This process produced an almost painless transition from the utility's present practice to the use of a modern microprocessor system. The system being addressed was a transfer scheme.

A transfer scheme is a combined protection and control system that accomplishes the transfer of load from one source to another when the load's primary source is lost. This is generally accomplished through a tie breaker. See Figure 1.

The general functions of a transfer scheme are to provide overcurrent, and possibly other, protection for the feeders serving the two loads. If the scheme senses that one of the sources is lost, it must then isolate the lost source, and initiate the transfer of the affected load to the alternate source. Once a transfer occurs, it should then provide all of the required overcurrent and other protective functions to

Figure 1: Typical Arrangement of a 3-Breaker Transfer Scheme



the load via the tie or alternate source breaker. Should the primary source returned to service, the scheme must re-connect the load to its primary source. In all cases, the scheme must prevent any type of automatic transfer or restoration to take place if any of the protective relaying has tripped.

Many subtle variations of such a transfer scheme exist, including whether the tie breaker is normally open or closed, whether one breaker must close before another opens, or whether the breaker waits to close until after the other opens, and so on.

II. Present State of the Art

Transfer schemes have generally been implemented in one of the following fashions:

Discrete relays and hardwired logic. This method is used extensively but exists today primarily in legacy applications. Relatively few new installations of this type are probably considered due to their complexity. However, implementing another installation of an already designed and proven, albeit expensive, transfer scheme may be preferable to designing a new one from scratch. Draw-backs to this method are complexity, high costs, difficulty in troubleshooting, severe limitations and costs in making modifications to the scheme, and poor to non-existent event record keeping.

Relay PLC Hybrid Schemes: Here, relays are used for traditional protective functions, and programmable logic controllers (PLCs) are used to implement the transfer logic. This method is a dramatic improvement over discrete schemes, however drawbacks remain, including the need to obtain PLC programming skills, the selection of an appropriate PLC, which are generally not designed for utility applications, and the expense of the PLCs. Problems which are not addressed from the discrete method are poor records of transfer events, difficulty in troubleshooting, the need for a programmer to make changes to the logic, and lots of interconnecting wire.

Multi-Microprocessor Relay Schemes: In the past few years, a few microprocessor based relays have been introduced which, when interconnected in a certain fashion and set in a particular way, can implement the complete protection and control scheme using as few as three of these relays. This is a more elegant solution, but it still remains expensive, is difficult to coordinate event records from each relay to document a transfer, and requires coordinating scores of settings among the three relays to make changes to the scheme

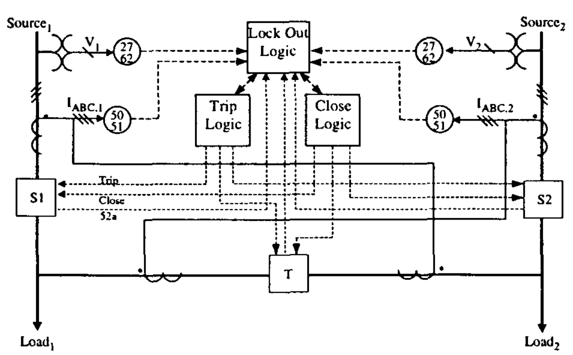
All of the above solutions suffer from one common shortcoming: they depend on multiple, independent devices to implement what needs to be a seamlessly coordinated process.

The user utilizes transfer schemes throughout their service territory as one level of premium service. These schemes have traditionally been implemented by the discrete relay and hardwired logic method.

Figure 2 shows in block form the required discrete electro-mechanical protective and control devices as well as their interconnected wiring for the existing transfer scheme. The basic functions of the utility's implementation are as follows:

- Upon loss of source voltage, transfer the de-energized load to the remaining source.
- If enabled, perform either open or closed transition back to normal system configuration upon recovery of source voltage.
- Perform phase and ground, instantaneous and time-overcurrent protection individually for both load circuits.
- Intelligently trip the proper breaker for overcurrent events regardless of the transfer configuration.

Figure 2: Connectivity Diagram using Discrete, Electro-mechanical components



Although the existing scheme has proven itself in service, the operating utility desired a migration away from electro-mechanical components. The belief was that a scheme based upon microprocessor technology would yield enhanced flexibility and features, be comparable or lower in overall costs, and assuage concerns over maintenance of older components.

Obviously, the wiring and testing of such a complicated panel of components is not trivial. A simple one-for-one functional replacement of the existing electro-mechanical devices with digital components will add new-technology features but still require tedious interconnections. Therefore, a solution was sought that would:

- Exploit the ability of new-technology to provide an integrated solution;
- Ensure that most interconnections of the protection and logic sub-components would be contained within a single hardware platform.

III. Solution Development

Conversion of the utility's transfer scheme to a single conventional microprocessor based relay platform would have required the definition of the inputs and outputs and a characterization of the functionality desired by the system through a series of flowcharts. The manufacturer of the relay would then need to determine the best way to implement these requirements in their particular hardware platform. Extensive development effort in some programming language, such as C++, with an occasional mix of some assembly language routines, would inevitably be required. At that point, testing could begin.

The fact that the user already had the complete system designed using discrete components would have minimal impact on this process; both the user and the manufacturer would essentially have to start from scratch.

Rather than following this approach, a universal protection and control platform that featured modular hardware and a graphical, object oriented programming environment was employed to combine the transfer control logic and protective functions. The universal platform was selected since both hardware and software development time would be minimal: the modular hardware permitted inclusion of circuit elements to satisfy the analog input and contact input/output requirements; the graphical programming environment allowed for rapid generation and integration of the logic and control functions. Only a quick development cycle, such as that afforded by the universal platform, would yield a cost-effective solution to this relatively low-volume customized scheme and at the same time, meet the utility's desire to replicate the functionality of the existing scheme with a single device.

III.A Description of the Development Process

The programmable nature of this universal platform allowed the system to be developed primarily in one of two ways:

1. Via a complete redesign effort, employing new ideas, processes, and algorithms, or;
2. By copying exactly the existing scheme with all of its quirks using graphical objects that mimic the function of the existing discrete devices.

The first method is essentially equivalent to the process that would be followed for development in a conventional non-universal platform. Though the process would still be shorter than using C++ and Assembly programming, it would be more time consuming than desired and result in a more expensive development effort.

Conversely, the second method would allow for very rapid scheme development as the designer could essentially copy the existing system design. As long as the system looked like what already existed, the functionality could be assumed to be the same. The user would not have to spend time creating a detailed functional requirement specification.

The final development effort used a mix of the two methods, allowing for rapid development, but taking advantage of certain capabilities of the system that were not available in the discrete components system previously used.

III.B Description of Hardware & Software

The hardware system provided configurable analog and digital inputs and outputs, twelve programmable front panel metering displays, eight programmable targets, a 4 line by 20 character LCD display, and a set of pushbuttons that could be configured to implement control functions.

The programming software allows both settings and scheme logic to be quickly modified using an intuitive graphical interface. Logic design utilizes standard logic symbols, not complex formulas or ladder-logic, and places no limit on the complexity of logic, nor the number of logical elements. Complex structures, such as overcurrent relay elements, are represented as graphical objects, which can be added or removed from the scheme through standard Windows drag and drop techniques.

III.C Human Machine Interface (HMI) Design

Discussions with the operating utility permitted the relay manufacturer to gain understanding of how the front panel should be designed. The relay has several targets which were assigned to display status of the transfer scheme in a manner consistent with the operational practices and expectations of the utility. The targets were assigned using the relay's graphical programming software. Custom illuminated target labels were generated with a word processor template and a printer loaded with transparency medium. Given the fixed number of available front panel targets and the customizable nature of the platform, some thought was necessary to determine what status information was to be displayed. The question which needed to be answered by the operating utility was: "what information is most important for an operator who first approaches the relay in the field?" If the utility considered transfer functions more important, then the targets would be assigned to reveal the OPEN or CLOSED state of each breaker and whether the transfer logic is in the automatic or manual mode. If protection functions were considered more important, the targets would be assigned their more traditional role of overcurrent fault diagnostics.

In addition to customized target information, the relay's twelve front panel meters may be assigned to display numerous signal levels available to and generated within the relay: instantaneous current of either or both loads, demand currents, maximum demand currents, powers, kWhs, power factors, voltages (actual, maximum, minimum), etc. As with the targets, the operating utility determined what values were to be displayed on the front panel. A word processor and a laser printer were again used to create the label inserts to properly identify the customized meters.

In case there were too few front panel meters and targets to display all the status and signal values desired by the utility, the lower priority information could be assigned to the relay's front panel LCD. The relay's graphical programming software also provided ease and flexibility in the design of the front panel menu layout. A discussion with the utility was appropriate to gain input and make suggestions for designing the menu structure which may be flat, nested with several layers of sub-menus, or any combination in-between.

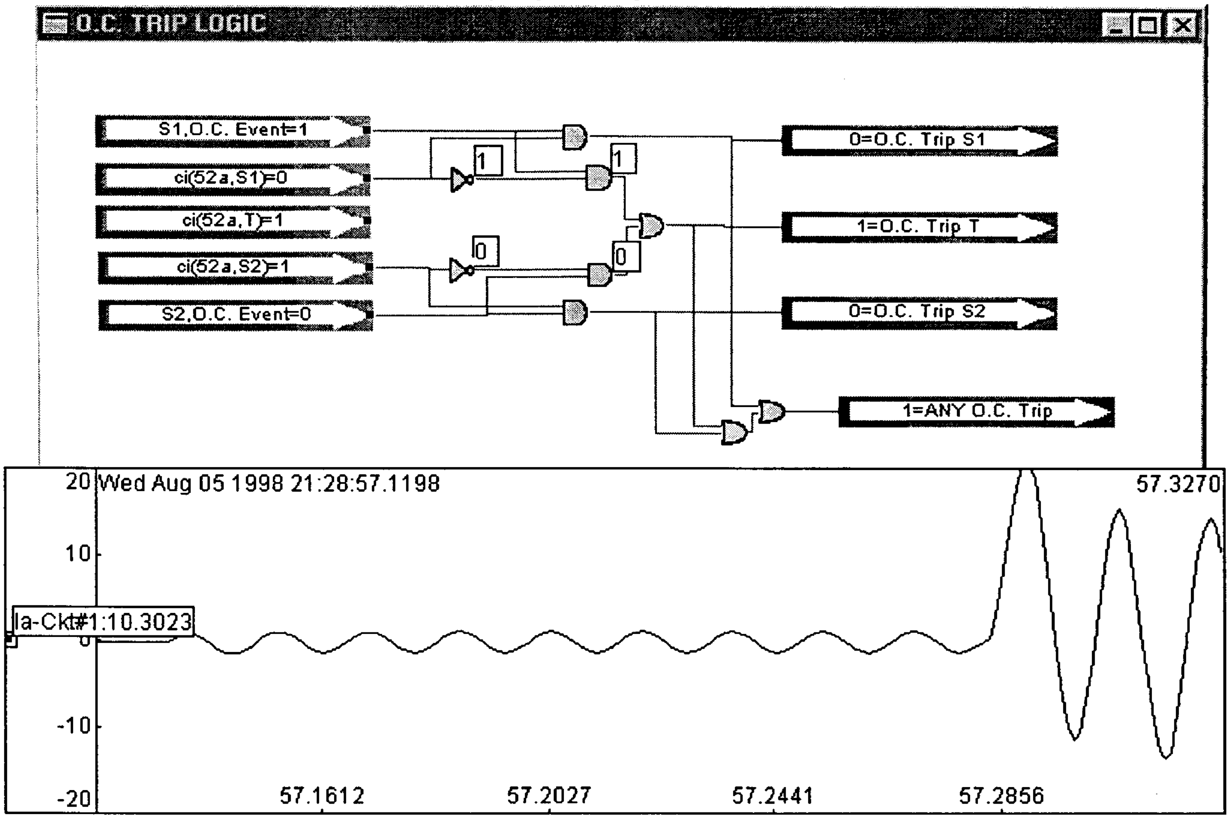
IV Testing

The integration of several protection and control elements, as performed in this transfer scheme, presents challenges for the design engineer regarding testing and verification. Two testing techniques were utilized in the development of this scheme: virtual testing provided by the relay platform's programming software and live testing using the manufacture's real-time power system simulator (RTPSS).

IV.A Virtual Test Set

The programming environment of the relay platform provides extensive capabilities for testing the scheme in a virtual mode. The Virtual Test System (VTS) allows the developer to modify internal settings associated with analog and digital inputs to adjust synthesized driving signals to the relay logic. This would be analogous to live signals being injected via a relay test-set. The synthesized signals are combined with scheme logic and control blocks to permit the developer to assess design viability. The virtual test may proceed in a sample-by-sample fashion allowing detailed examination of logic signal interaction. For example, Figure 3 shows software views of a simple logic block within the scheme and the oscillogram of a virtual current input waveform. The function of the digital logic component shown is to determine which breaker to trip based upon breaker status and which circuit overcurrent element asserts.

Figure 3: Virtual Test Set View of Programming Logic and Input Waveforms



In this example, the 52a contact input signals indicate the state of the breakers: both loads transferred to Source 2; Source 1 breaker open. The virtual current waveform was set to simulate an overcurrent condition on the Circuit #1 input. Protective blocks – not shown here – recognize the current as a fault event and assert the internal “S1 O.C. EVENT” signal. The signal path shown above results in the proper assertion of the signal for tripping the Tie Breaker (“O.C. TRIP T”).

Logical sub-blocks may be testing separately and used throughout the scheme as necessary in a manner analogous to procedures in structured programming. Or, complete scheme logic from analog input to contact output may be virtually tested without actual hardware.

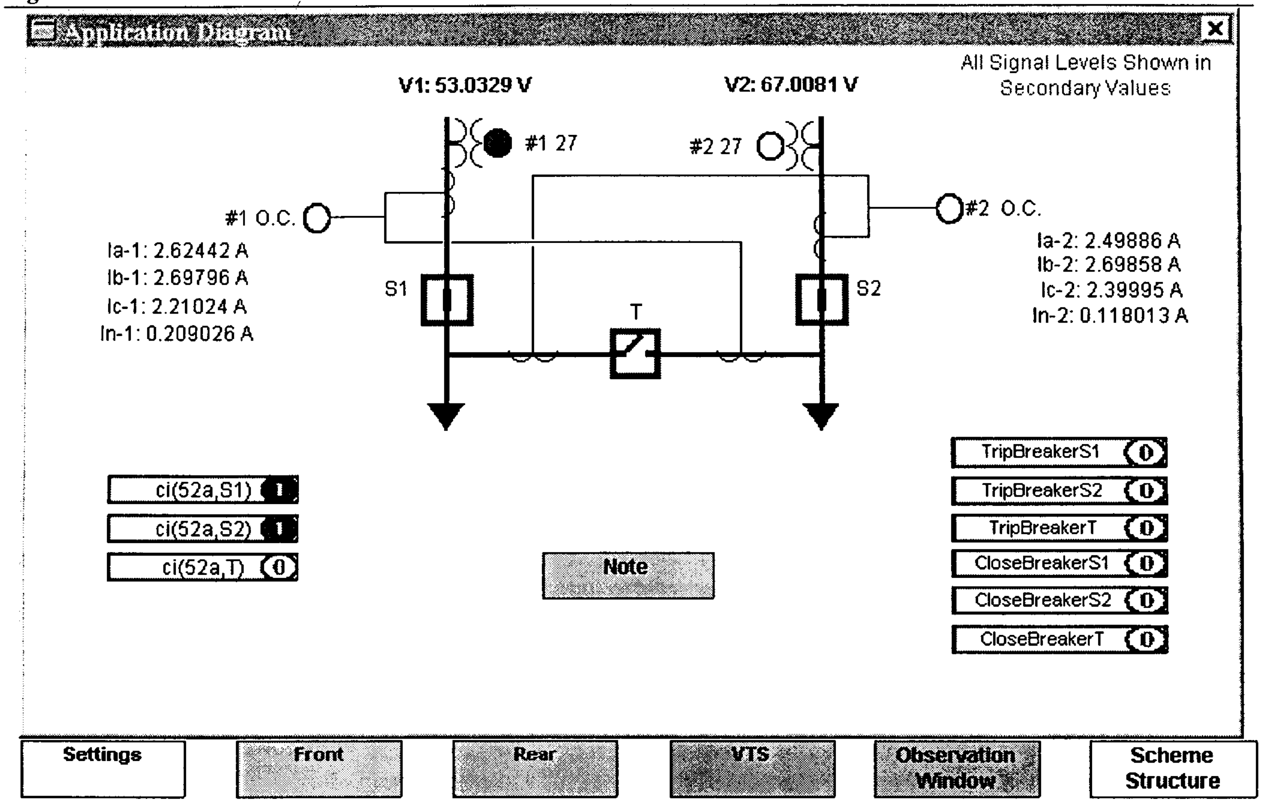
IV.B Real Time Power System Simulator

The VTS was employed to verify scheme operation as new sub-blocks were generated. But when the scheme was considered complete, the program file was compiled and downloaded to the relay hardware to permit final live testing. Because the logic of this scheme is based upon several feed-back signals from breaker status contacts, the manufacturer's Real Time Power System Simulator (RTPSS) was used instead of a bench-top relay test set. The RTPSS uses a low-signal level analog power system model with high-fidelity amplifiers to condition test voltage and current signals to proper levels for injection into the test relay. Electronically-controlled switches serve as breaker models or fault inception mechanisms. Extensive data acquisition and data processing capabilities permit rapid and accurate assessment of relay response to various simulated events.

The breaker models, voltage sources and load models were assembled to replicate exactly the relay's proposed environment. Current and voltage amplifiers interfaced between the analog model and the relay's analog inputs. The breaker models' trip, close and status signals were connected to the relay's contact I/O with an appropriate wetting voltage. The real-time nature of the simulator permitted rapid testing of numerous combinations of realistic and hypothetical scenarios: loss/return of supply voltages, overcurrent events at various locations under various system states, personnel intervention (manually altering the system state). In following the case list for the real-time simulator, some logical problem not evident from VTS testing were quickly identified. Correction of the problems required:

- Identifying and amending the faulty logic in the relay's graphical software environment;
- Recompiling the scheme;
- Downloading the modified scheme to the hardware;
- Re-testing to assure expected response.

Figure 4: Transfer Scheme Windows Interface Software



Because of the programming structure of the platform, most changes could be implemented and tested in less than one day.

V Windows Interface Design

The system allows for a completely customizable Windows interface to be created for each application. The top level interface supplied is shown in Figure 4. Salient real time features are:

- An interactive mimic board style display which, when connected to the relay, displays changes in breaker state, faults, and contact I/O status;
- Real time measurements obtained by the relay (also available in digital form via Modbus, DNP3.0 and UCA 2.0 formats).
- One "click" access to the device's settings, front and rear panel connection diagrams, Virtual Test Set settings, oscillographic event records, and program structure view.

The system also provides the ability to view a fully integrated oscillographic event record encompassing waveform displays and contact and protective element status for protection and control portions of the scheme. See Figure 5 for a typical graphical event record.

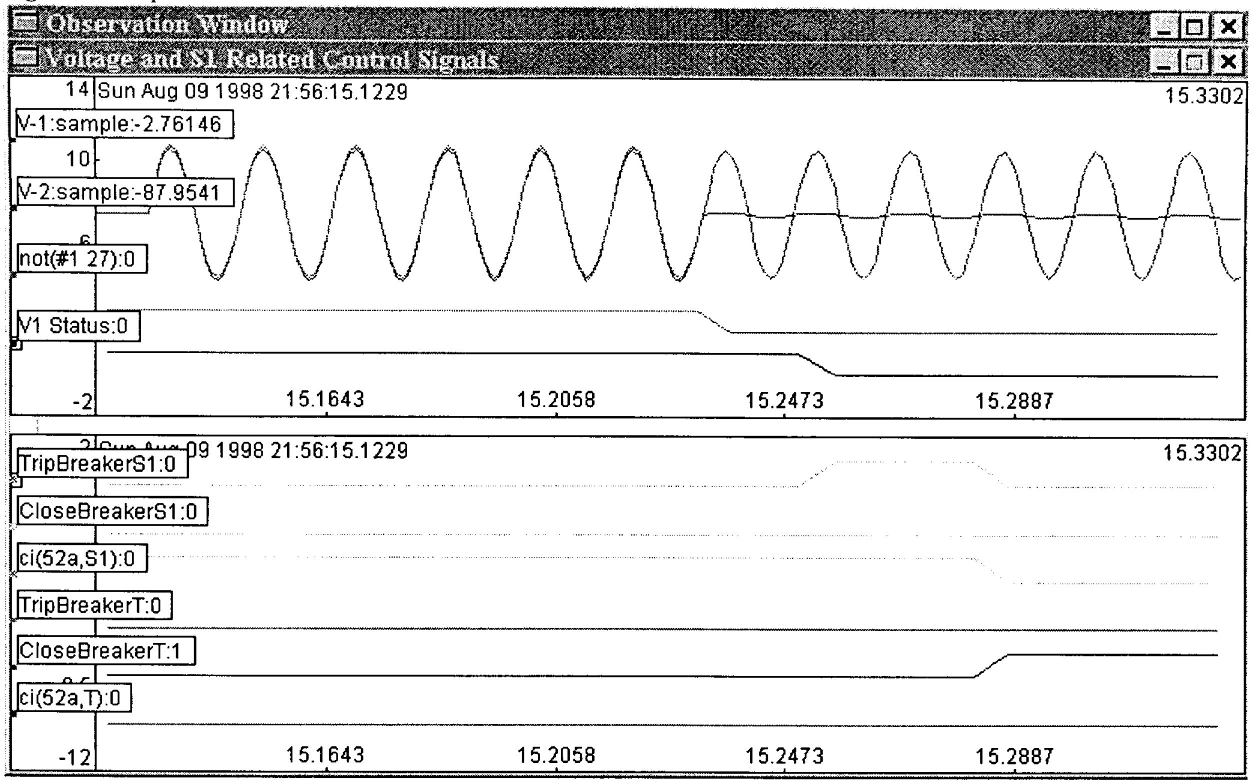
VI Future Enhancements

Growing familiarity with the capabilities of the universal relay permitted the operating utility to consider enhancing the existing control and protection functions to exploit new features to add robustness or reduce costs.

The relay's programmable front panel soft keys may be used to manually open and close the breakers to reduce costs associated with control switches. Available timers can be used with breaker status signals and measured currents to provide breaker failure indications. Synch-check functions can be added to supervise the close-transition sequence. Although unrelated to the transfer nature of the scheme, the utility is also considering the addition of contact inputs to be used with the sudden pressure relays of nearby transformers (for this typical vault application) and integrated into the scheme to aid in fault diagnostics and eliminate existing lock-out relays. The number of CT banks could be reduced by one if the remaining three CTs are input directly to the relay (instead of the existing totalized configuration). In addition to the cost saving of fewer CTs, fault directionality would then be possible, if desired.

Even after being placed in service, these, or any other, new features may be added to the hardware simply by downloading an updated, and fully tested, scheme file to the relay with a portable computer.

Figure 5: Graphical Event Record



VII Summary

1. The use of a universal protection and control platform successfully enabled the user to implement a modern, integrated, and custom transfer scheme.
2. The object oriented programming nature of the system permitted existing one-line and three-line drawings to be the primary resource needed to develop the new scheme. This greatly reduces the necessary involvement of utility personnel to describe the desired behavior of the protection and control scheme.
3. The use of the platforms built-in virtual test set contributed to the rapid development cycle as testing could be performed immediately following logical sub-component development.
4. Any changes to the scheme desired in the future can be made rapidly and simply, thereby protecting the initial investment and ensuring a long useful life of the system.

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Biographies

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