Comparison of SEL-2020 Star Network to Shared Networks

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ABSTRACT

Most modern substation automation systems use a local device to communicate with Intelligent Electronic Devices (IEDs) in the substation and to remote users of the substation's data (e.g., system dispatchers). In a star network, each IED communicates with its own channel to a "hub." In a shared network or bus topology, IEDs take turns using a shared communications channel. This document explains why SEL recommends a star topology for most substation automation applications.

BACKGROUND

To address substation automation, we first examined the fundamental issues. We identified the following key items:

- The most useful solution should include methods to communicate with a multitude of diverse devices from different manufacturers. The solution should address installed devices (legacy IEDs).
- Systems that use optical fiber instead of wire in the substation are safer for equipment and personnel, and are not susceptible to radiated electrical noise.
- Customers expect protective relays to be in service without modification for decades, as contrasted to system integration practices that change on a two- or three-year cycle.

These items were among the key driving forces leading to the development of our SEL-2020 and SEL-2030 Communications Processors, the SEL-2800 and SEL-2810 Fiber-Optic Transceivers, and our star network design.

The SEL-2020 Communications Processor includes 16 EIA-232 ports, which the user can set to communicate with a wide variety of SEL Relays, other manufacturer's IEDs, and "master" or "host" devices. The SEL-2020 can communicate with master ports using DNP V3.00 Level 2 Protocol, Modbus Binary RTU Protocol, simple ASCII commands, and user-defined command strings. The user-defined command strings handle virtually any device of any manufacturer with any EIA-232 link, i.e., all IEDs.

The SEL-2030 Communications Processor includes the features of the SEL-2020 plus the ability to support plug-in cards for various applications utilizing a separate processor. The first two communications cards that will be available are the SEL-2701 Ethernet Adapter and the SEL-2711 Modbus Plus Card.

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Figure 1 depicts a substation one-line diagram using SEL protective relays and an SEL-2020 Communications Processor to serve multiple remote and local data users.

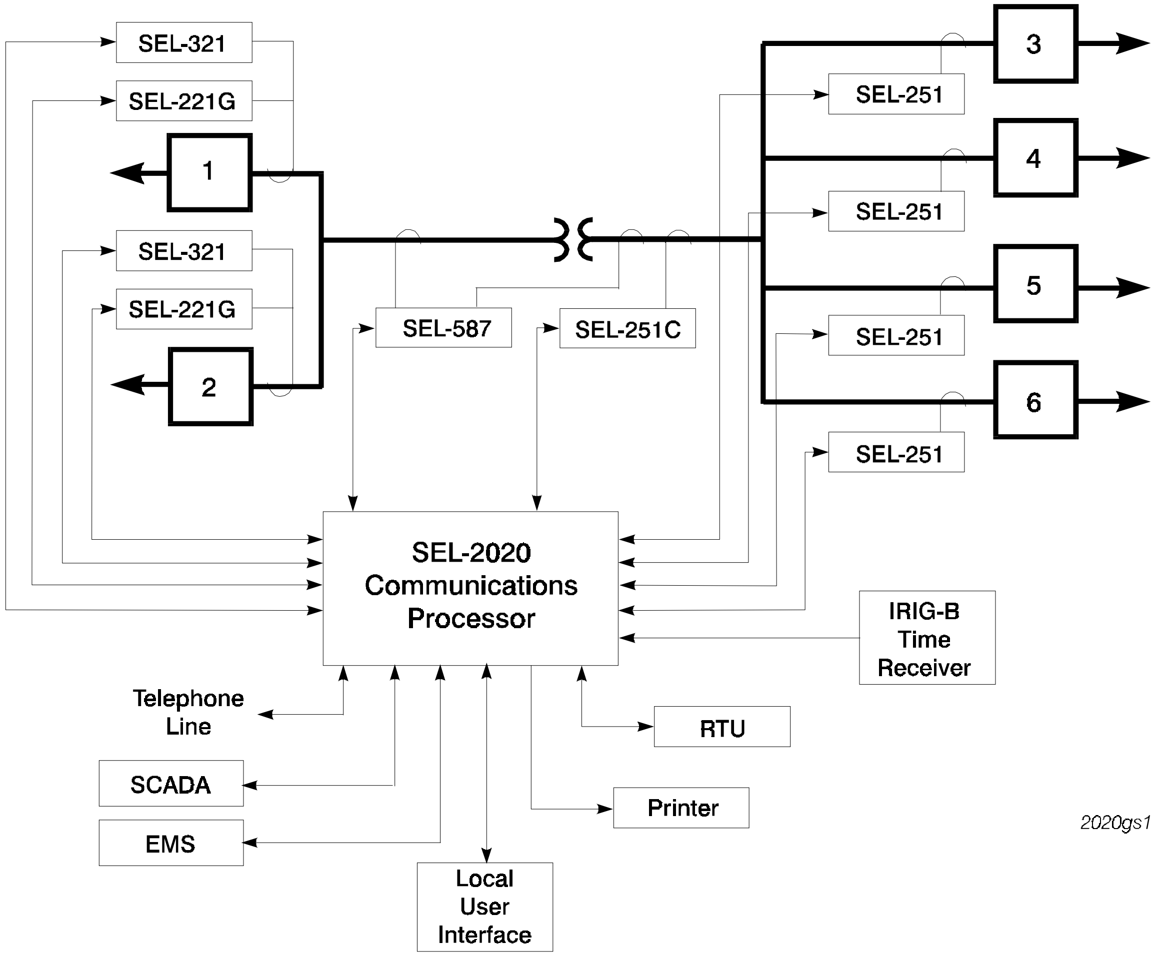


Figure 1: SEL-2020 Example Star Network Diagram

The following paragraphs enumerate many of the reasons for using the SEL-2020 Communications Processor and SEL Relays and products in a cost-effective star system:

1. Use Low-Cost, Safe, Point-to-Point Fiber-Optic Links

Optical fiber connections are safer than metallic wire for personnel and equipment because the fiber is an insulator. Ground rise potential and other high-voltage transient phenomena are isolated by the fiber, so they cannot injure personnel or damage equipment. The fiber also provides immunity from electrical interference with the communications signal. Using optical fiber results in a system that is safer, has a higher availability because equipment is protected from damage, and has a channel that does not suffer from interference.

The lowest-cost and least-complex fiber-optic transceivers support point-to-point communications. Generally, multidrop fiber transceivers internally consist of multiple devices that do the multidropping on the electrical side of the transceiver and repeat signals through an additional transmitter. Therefore, they cost more than point-to-point transceivers, and the additional parts reduce the reliability of the device and the system.

The SEL-2800 and SEL-2810 Fiber-Optic Transceivers are built in compact packages that directly mount to the subminiature 9-pin “D” connectors on the SEL-2020 and some SEL relays. For other relays and IEDs, use an intermediate adapter cable. Both devices are powered by EIA-232 signals and are connected by a two-fiber cable to the other end of the link. The SEL-2800 provides bidirectional communication at up to 38.4 kbps. The SEL-2810 provides bidirectional data up to 19.2 kbps and transmits IRIG-B time code from the SEL-2020 to the IED using the same fibers.

It is easy to determine the cost of the fiber-optic advantages when contrasting two systems. The SEL-2020 star topology works well with either metallic links or fiber-optic links. If you are comparing the star system to a metallic multidrop network, do not include the cost of fiber-optic transceivers or optical fiber. Then, if you want to evaluate the costs of the added benefits of the fiber, add the transceiver and fiber cost, and subtract the metallic cable cost from the star system.

2. Provide a Full Integration Solution

“Substation Automation” can encompass many different requirements and solutions. In some cases, it may include the means to communicate with multiple devices in a substation through a dial-up network. It can be a distributed system that replicates the functions of an RTU or a complete distributed digital control system. The local Human Machine Interface (HMI) may not be present, may be a PC or workstation using a standard or custom HMI package, or may be a simple “dumb” terminal. Figure 1 shows many of these possibilities. In many cases, the SEL-2020 and connected IEDs can provide complete integration solutions. For dial-up telephone access, the SEL-2020 can typically provide the complete substation integration required.

If the input and output (I/O) needs for the substation are met by the combined I/O of the IEDs and the SEL-2020, and one of the protocols in the SEL-2020 or SEL-2030 is used by the customer’s SCADA master, then a substation can be connected to a SCADA system without the additional expense of an RTU.

Most off-the-shelf HMI packages can use Modbus or DNP V3.00 protocol, so these packages are easily integrated with the SEL-2020 or SEL-2030 Communications Processors.

3. Serves Many Data Users With Preprocessed Information

You can set more than one port on an SEL communications processor to communicate with master or “host” devices. Example data users include:

- Dial-up telephone port for access by protection engineers
- Dial-up telephone port for access by metering department
- Dial-up telephone port to call pager
- EIA-232 Modbus or DNP V3.00 link to local PC with HMI package
- EIA-232 ASCII link to local printer
- EIA-232 Modbus or DNP V3.00 link to local RTU
- EIA-232 Modbus or DNP V3.00 link to remote SCADA

With the SEL-2020, you can set each port to the appropriate protocol or user-defined command set to allow data access for each application. Data from each IED are saved in the local database and are accessible to multiple data users. Each master port can use a different protocol or user-defined command set to serve the needs of its data user. The use of multiple Modbus ports can reduce the host data acquisition time by allowing multiple unique blocks of data to be retrieved simultaneously.

The SEL-2020 provides an innovative way to collect data from all classes of IEDs and, in turn, makes new types of data available to the system. This information can be employed to enhance historical business practices. One such example is Appropriate Internal Maintenance, AIM, of the IEDs. Predictive maintenance schedules are driven by performance characteristics and time-in-operation values, rather than simple time since installation scheduling.

4. Easily Communicate With SEL Relays

The SEL-2020 and SEL-2030 Communications Processors communicate with legacy SEL relays and new SEL products. Older SEL relays use ASCII commands optimized for human-machine interaction. The ability to communicate with each of these "dialects" is built into the SEL Communications Processors. We added binary communications to retrieve *Fast Meter* information and to provide *Fast Operates*. These binary commands are interleaved with ASCII communications to help support multiple data users. This interleaved data mechanism is described in detail in *SEL Products and Features Make System Integration Easy*. The communications processors and new SEL products automatically exchange configuration information so that the communications processors can learn about the available data and commands from new SEL products without the need to change the program in the SEL-2020 or SEL-2030. This automatic match of the relay to a stored or communicated configuration prevents a system integrator from investing multiple person-years of programming effort to reinvent and retest these communications dialects. These dialects can be expected to continue to change as new features are added and new devices are developed.

An autoconfiguration setting allows the communications processors to access data appropriate for the connected SEL product. "Job-Done" setting examples show how to extract the data available from each device.

5. Easily Communicate With Other Intelligent Electronic Devices

One of the most powerful strengths of the SEL-2020 and SEL-2030 Communications Processors is their ability to communicate with devices in an existing protocol or dialect without the need to write custom programs. Their setting capability allows you to define requests for data and to interpret or "parse" the responses to extract data of interest. SEL also has a growing number of "Job-Done" examples that show the precise cables and settings to be used with a growing library of IEDs, which are easily entered into the command and response dialogs. Many devices use simple ASCII commands. Many meters use the MV-90 protocol. No programmer has created an MV-90 protocol driver in the SEL-2020 but, by observing the subset of request and response data needed to extract meter information from an MV-90-compliant meter, we can extract the meter information through settings in the SEL-2020. In some cases, it is also feasible to listen to the data exchange between two other devices in the system, and extract data from their dialog to use in the SEL-2020 database. Contact SEL for "Job-Done" examples for any IEDs that interest you.

6. Choose IEDs That Best Fit Your Use

The ability to easily integrate SEL relays and other manufacturer's IEDs gives you the freedom to select the devices for each application that best fit your needs in terms of cost, features, and performance. You can consider the merits of the devices for their primary purposes without being limited by availability, cost, and schedule issues regarding protocols supported by the device. For example, SEL offers feeder protection options that include low-cost time-overcurrent protection for two feeders in one SEL-501-2 relay, additional ground current sensitivity and front-panel features in the SEL-551 Relay, a complete feeder protection package in the SEL-251 Relay, and advanced distribution line protection in the SEL-351. They all communicate with the SEL-2020 and, in turn, the SEL-2020 can communicate with most systems. Similarly, if you want to select the best meter or other device for a specific purpose, communications with the SEL-2020 allow you to select the meter on its metering merits independent of most communications issues.

For existing installations, the ability to communicate with legacy IEDs can save you the trouble and expense of replacing IEDs for communications network reasons. Also, customers expect protective relays to be in service without modification for decades, as contrasted to system integration practices that change on a two- or three-year cycle. An intermediate device like the SEL-2020 buffers the protection from changes due to faster cycle protocol or communications decisions.

7. Synchronize Clocks

Accurately time-tagged event reporting eases analysis. Accurately time-tagged metering information is more useful for state estimation than transducer data received after indefinite SCADA delays. SEL introduced time synchronization of relays to the industry in 1985, in the 100-series hardware.

When SEL developed the SEL-2020 Communications Processor, one goal was to eliminate the need for a separate time-code distribution means. We accomplished this goal by including an IRIG-B time-code demodulator in the SEL-2020. Each of the 16 rear ports includes a buffered demodulated IRIG-B time-code output, which directly drives SEL relay time-code inputs. Now, a single cable from the SEL-2020 to the SEL relay transfers not only the EIA-232 signals but also the time code. The SEL-2810 Fiber-Optic Transceivers, with a two-fiber cable between the SEL-2020 and IEDs, transfer bidirectional EIA-232 signals and IRIG-B time code.

The SEL-2020 also includes a clock/calendar with battery back-up. Normally, the demodulated IRIG-B outputs are synchronized to the SEL-2020 time-code input. However, if no input is present, the SEL-2020 continues to generate demodulated IRIG-B outputs based on the internal clock/calendar to keep all of the relays connected to that SEL-2020 synchronized. This convenience eliminates or postpones the need for a time-code receiver in many applications.

Generally, systems using multidropped networks do NOT have the capability to accurately synchronize the time through the network. High-speed PLC time-tagging cards usually employ a separate time connection rather than attempting time synchronization through the network or backplane.

8. Monitor 16 Local Digital Inputs

You may order the SEL-2020 Communications Processor with an option including 16 digital input points and four digital output points. One way that you can use these points is to monitor the alarm output of each relay or other IED. This provides an independent indication of the device status and helps you diagnose whether a problem is in the IED or in the communications.

You can use the local digital inputs to retrieve data from local selector switches that select logic or setting groups used by more than one IED. These inputs can also be used in local logic calculations. One such purpose is the ability to prevent remote operations, thus protecting personnel during maintenance activity. This is done using a remote station/local input in the SEL-2020 logic.

Or, you can use the SEL-2020 input terminations to bring in "loose" digital input points and save the added expense, perhaps longer wire runs, and panel space that you would need to add I/O locally or remotely to an RTU or PLC system.

9. Distribute Logic Processing to Appropriate Level

The SEL communications processors include local SELOGIC® Control Equations. The commands in the SEL-2020 allow you to perform logic at the appropriate level, close to the relays or other devices involved. Contrast this to a system that sends all data to a central location for processing and then returns a resultant control action. The distributed system using local SEL-2020 Communications Processors performs the control autonomously, quickly and locally, on the set of data from the local IEDs connected to it. Where as, the centralized system requires transmission time and bandwidth to get all of the data to a central processing point, performs all of the logic on the big data set, and then must transmit the results back though the communications channels to all of the actuating IEDs. Example uses of local logic include changing settings based on time-of-day or power system connection inputs, using loss-of-potential detection in one relay in the logic control equations of other relays on the same bus, changing logic based on a single input to the SEL-2020, which indicates a specific testing or system condition, and forwarding data retrieved from one IED to another IED without the data having to pass through the central host.

10. Easily Diagnose Communications Problems

The LED indicators for each channel on an SEL-2020 Communications Processor make it very easy to see if there is communications traffic with that particular node. You can observe whether data requests are being sent to the IED and whether the IED is responding. You can also detect a locked up transmitter by observing a constantly asserted LED. Contrast this to a multidrop network, where a single IED can fail and stop communications for an entire network. To determine which device has a communications fault is a process similar to the frustrating troubleshooting of old series-connected Christmas tree bulbs.

11. Reliability: Designed and Proven in the Substation Environment

The SEL-2020 Communications Processor uses the same rugged design used in our protective relays. It operates reliably over a -40 to +85°C temperature range. It can be powered from either the DC station battery or from AC. It contains no moving parts, so it is not prone to the failures that you must expect from rotating disc drives or other low MTBF components.

12. Use Ports in Parallel for Performance

In a star topology, each node (device) has its own channel, as contrasted to a multidrop network where each node must wait for its turn to use the shared medium. For example, if an SEL-2020 is communicating with 15 IEDs at a data rate of 38,400 bits per second, the data transfer rate is equivalent to a 576,000 bits per second channel. A multidrop network also has the additional overhead of addressing each node and disconnecting from each node. The overhead, including multidrop addressing or token passing, can range from 15% to 60% or more or an equivalent network speed of 662,400 to 921,600 bits per second to achieve the same update rate in the local database. GE Harris recently completed research evaluating high-speed substation network options. When bit errors on these networks were observed and evaluated, it became apparent that the token passing schemes were not reliable. They recommended using a star topology, incorporating switching hubs, on these high-speed networks to achieve a dependable system.

13. Minimize Channel Demand

For the connection from one level of a network to a higher level, the system architect can either send all data to the top level for processing or send only the appropriate subset of data to minimize the use of the channel. With the SEL-2020, you can build blocks of data that contain only the information needed by the next level. Many systems are designed to acquire all data all of the time because the designers did not have a communications processor to provide an easy way to get just the data of interest. For example, if the only information of interest in a real-time display is a single current reading for current on a line, there is no reason to transmit all three phase current readings through the system. You can select to send just the current of interest (e.g., A-phase or positive sequence only), reducing the channel requirements to one-third of the previous example. Reducing the channel demand also reduces the strain on the computer resources at the other end of the channel. The host has less data to deal with, so it does not need to allocate processing power or memory for the larger data set.

14. Declare Independence from IED-Controlled Data Block Definition

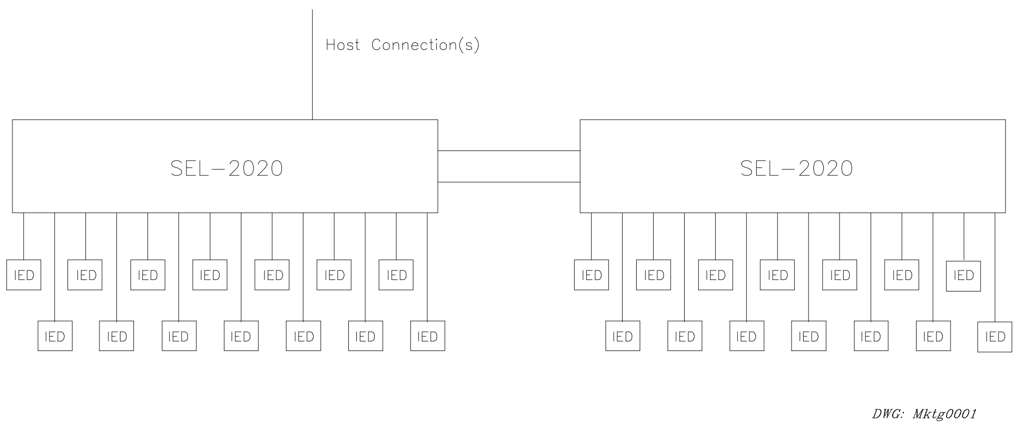
Many host systems are designed to acquire data from IEDs in predefined blocks. If you want to retrieve data that are not in adjacent register addresses, you typically must read a large block of data and then ignore the data that you did not need. Or, you must spend the communications overhead on making multiple requests to retrieve multiple responses. In the case of Modbus and other PLC protocols, host drivers internally translate individual data requests into single large block read. In the case of DNP V3.00, there is significant overhead associated with each data request. By using the SEL-2020 SET M command, you can map exactly the data of interest into a contiguous block of addresses, so that the next level can optimally retrieve the information. This makes optimal use of the channel between the SEL-2020 and the host device.

15. Pay for Only the Appropriate Communications at Each Level

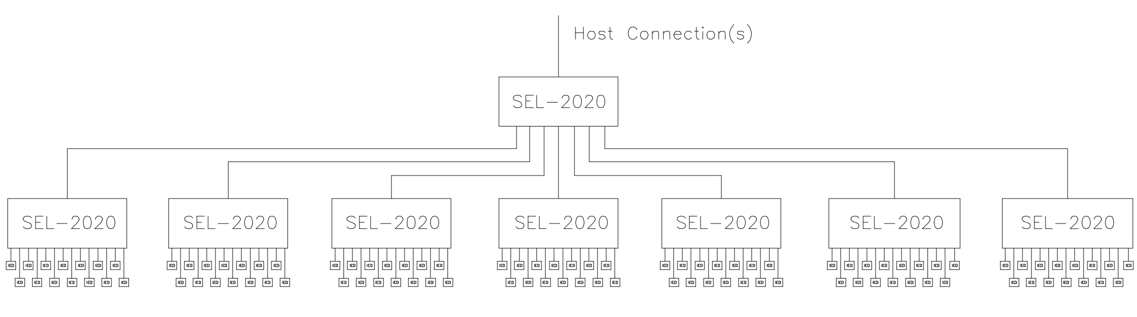
In a star network with the SEL-2020, each IED can communicate with one of its native protocols at a data rate appropriate for each IED. The SEL-2020 stores and blocks the data for transmission to other devices. In a system that uses a high-speed or proprietary network to communicate with data concentrators or IEDs with large data blocks, each node on the network has an associated cost. These costs are due in part to added components needed for the interface, added processor burden, added memory to support special protocols, added development costs for protocols, and license fees and captive component pricing for proprietary protocols. If other devices in the substations use a high-cost protocol, there is still an opportunity to save money in a star network subsystem. For example, suppose that the added cost to an end user for one node of XYZ protocol is $500. If the protocol is added into each of 15 nodes, this is an added cost of $7500. Incorporating the protocol into each device also may have limited the selection of the best IED to accomplish its purpose, compromising a protection or metering advantage with a communications protocol complication. By contrast, the SEL-2020 star, as an IED subsystem on an XYZ network, needs only one XYZ protocol node at $500 for a total price, including the SEL-2020, that's still less than half of the $7500 example. Best of all, you still have the flexibility to choose the best IED for the job, and you have the other advantages of the SEL-2020 star topology. You could use the money you save to buy all of the advantages of fiber-optic links, instead of paying for channel capacity that is underutilized by each node.

16. Easily Cascade SEL-2020 Communications Processors: Cost Effective and Fast

You can cascade the SEL-2020 Communication Processors to best suit your data propagation needs. They can be set up to poll IEDs and then each other in a parallel fashion as shown below. This allows each SEL-2020 to acquire data for all 28 IEDs.

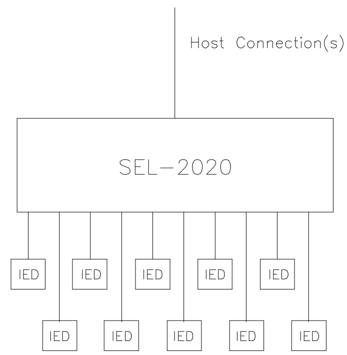


You can also cascade the SEL-2020 Communications Processors using a tiered configuration so that one, or redundant, upper tier SEL-2020s can acquire data from any number of IEDs polled by several lower tier SEL-2020s.



Example 1: SEL Star (10 IEDs)

By virtue of the star configuration, each IED has an independent and unique communication connection to the SEL-2020, which has one or several EIA-232 connections with the host. These host connections can be redundant or independent. Utilizing the SEL-2030, the host connections can be a hardware-specific high-speed network interface. Robustness is provided through these individual connections. Inherent noise and path failure of one IED does not affect the others. Performance is enhanced through communicating with all 10 IEDs simultaneously at up to 19,200 baud, and the parameters of each connection are independent. If any number of IED paths fail, the performance of the others is unaffected. The effective maximum refresh rate of the system database is the scan rate of the slowest IED connected because the host can acquire data from all 10 IEDs in each message exchange. Baud rate, protocol, and bit configuration are selectable for each connection, allowing you to choose the most appropriate IED regardless of communication constraints.



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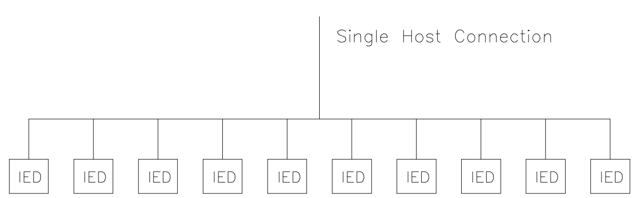
Example 2: EIA-485 Network(10 IEDs)

The EIA-485 network multidrops IEDs on a slow-speed bus with a single connection to the host. Robustness is limited by this single point of failure. The protocol must not be hardware specific, relying on the EIA-485 connection and common maximum baud rates of 38,400 baud in the IEDs. The network must communicate with each IED consecutively. Thus, while the performance of the star topology is virtually unaffected by the number of IEDs connected, the performance of this bus topology is inversely proportional to the number of IEDs connected. The effective maximum refresh rate of the system database is the sum of all the individual IED scan rates. If one IED path fails or experiences noise, the performance of all IEDs is drastically affected. Each IED must employ the same protocol and parameters, thus closing your choice of IEDs and dictating that they be procured with the network protocol. The onboard EIA-485 protocol can add an average $90 to the purchase price of each IED.



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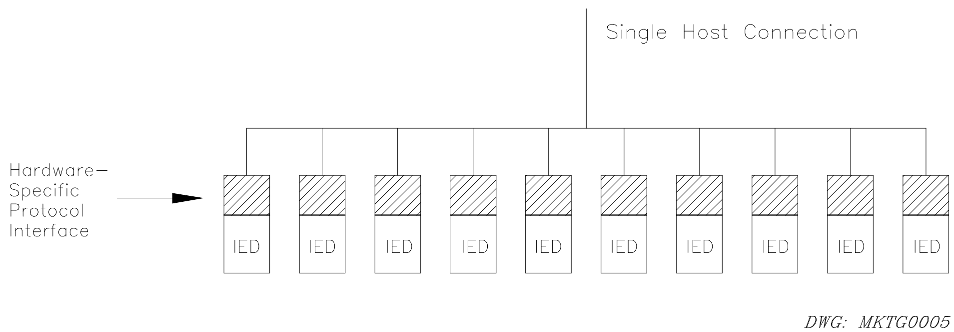
Example 3: Proprietary PLC Protocol Network (10 IEDs)

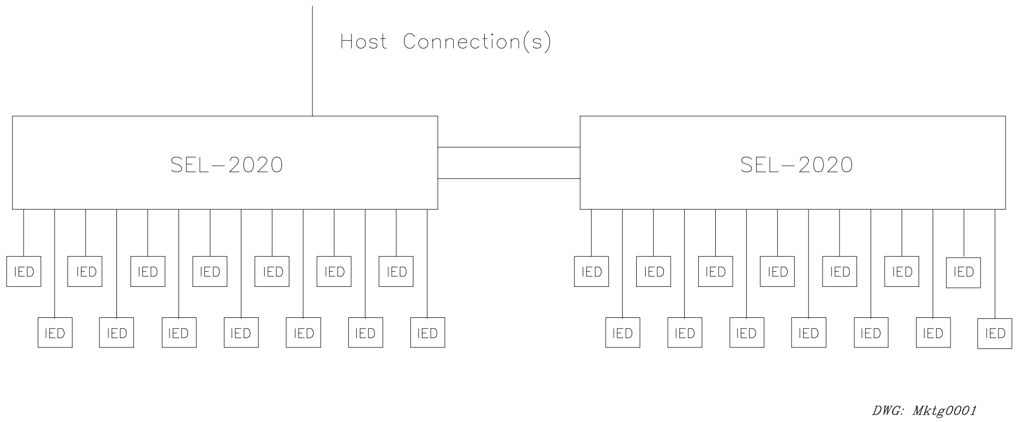
The proprietary PLC protocol network multidrops IEDs on a token passing bus with a single connection to the host. Robustness is again limited by this single point of failure. This hardware-specific high-speed protocol, though more flexible than its EIA-485 counterpart, still must communicate with each IED consecutively. Again recognize that while the performance of the star topology is virtually unaffected by the number of IEDs connected, the performance of this bus topology is inversely proportional to the number of IEDs connected. Since the effective maximum refresh rate of the entire system database is the sum of all individual IED scan rates; (see ***Section 12)***, when overhead of this high-speed multidrop bus is considered, the star configuration is comparable in speed. The token passing cannot eliminate the degradation of one IED path from affecting the performance of the others. Each IED must employ the same protocol and parameters, thus closing your choice of IEDs and dictating that they be procured with the network protocol. The onboard proprietary hardware-specific protocol adds an average of $500 to $1,000 to the purchase price of each IED.



	SEL Star 10 IEDs	EIA-485 Network 10 IEDs	PLC Protocol Network 10 IEDs
Robustness	**GOOD** Individual Connections, Multiple Host Paths	**POOR** Interdependent Slow Bus, Single Host Path	**FAIR** Interdependent Fast Bus, Single Host Path
Performance	**GOOD** Fast Data Refresh Time	**POOR** Slow Data Refresh Time	**GOOD** Fast Data Refresh Time
IED Selection	**GOOD** Select Any IEDs	**POOR** Protocol-Dependent IEDs	**POOR** Protocol-Dependent IEDs
Distributed Processing	**GOOD** SELOGIC Control Equations	**NONEXISTENT**	**NONEXISTENT**
Communication Overhead Minimization	**GOOD** Data Concentration	**POOR** No Concentration, IED Addressing Overhead	**POOR,** No Concentration, IED Addressing Overhead
Price Comparison	**FAIR** $0 Protocol ~$2800 SEL-2020, Inexpensive Media Transmission	**GOOD** $900 Protocol (10 @ $90), Inexpensive Media Transmission	**POOR** $10,000 Protocol (10 @ $1000), Expensive Media Transmission

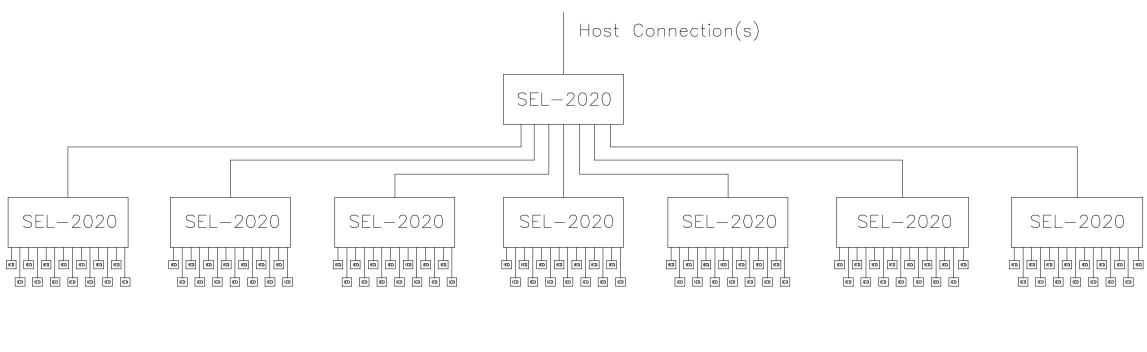
Example 4: Parallel SEL Star System (28 IEDs)

Two star configurations would be set up to communicate with all of the IEDs. Each star can talk to up to 16 IEDs, so pick the most convenient combination (for example, 14 on each star node SEL-2020). While each SEL-2020 can independently talk to the host, they can talk to each other as well. Therefore, each SEL-2020 can collect data for all 28 IEDs. This allows a single or multiple host data collection and transmission connections. If the SEL-2030 is used, these host connections can be redundant or independent, a mix of different protocols, or EIA-232 or hardware specific. Each IED maintains an independent and unique communication connection to the communications processor. Robustness and performance are as described in Example 1. The effective maximum refresh rate of the system database is the scan rate of the slowest IED connected plus the short scan rate of one SEL-2020 acquiring data from the other. Again, you can base each IED selection on its functions, rather that its protocol.



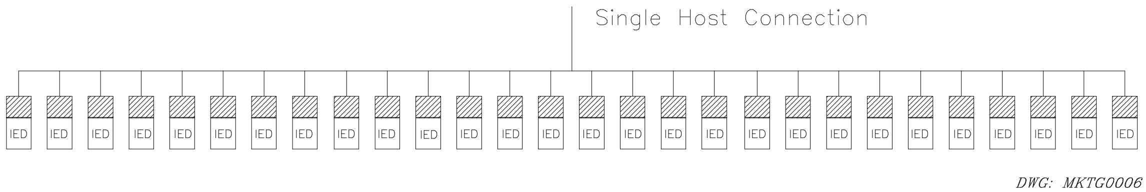
Example 5: Cascaded SEL Star System (100 IEDs)

Seven star configurations would be set up to communicate with all of the IEDs, 14 on each of 5 SEL-2020s and 15 on each of 2 SEL-2020s. One other SEL-2020 or SEL-2030 would then communicate with each other and these 7 lower tier SEL-2020s. Robustness and performance are as described in Examples 1 and 4. The effective maximum refresh rate of the system database remains the scan rate of the slowest IED connected plus the short scan rate of one SEL-2020 acquiring data from the other, since the upper tier SEL-2020s poll all of the lower tier SEL-2020s simultaneously.



Example 6: Proprietary PLC Network (28 IEDs)

In this case, the proprietary PLC protocol network multidrops 28 IEDs on a token passing bus with a single connection to the host. Robustness is as discussed in Example 3; however, the performance of this 28 IED bus topology is statistically slower by a factor of 2.8, since there are 28 IEDs compared to the previous 10. Again, each IED must employ the same protocol and parameters, thus closing your choice of IEDs and dictating that they be procured with the network protocol.



	SEL Parallel Star 28 IEDs	SEL Tiered Star 100 IEDs	PLC Protocol Network 28 IEDs
Robustness	**GOOD** Individual Connections, Multiple Host Paths	**GOOD** Individual Connections, Multiple Host Paths	**FAIR** Interdependent Fast Bus, Single Host Path
Performance	**GOOD** Fast Data Refresh Time	**GOOD** Fast Data Refresh Time	**POOR** Slow Data Refresh Time
IED Selection	**GOOD** Select Any IEDs	**GOOD** Select Any IEDs	**POOR** Protocol-Dependent IEDs
Distributed Processing	**GOOD** SELOGIC Control Equations	**GOOD** SELOGIC Control Equations	**NONEXISTENT**
Communication Overhead Minimization	**GOOD** Data Concentration	**GOOD** Data Concentration	**POOR** No Concentration, IED Addressing Overhead
Price Comparison	**FAIR** $0 Protocol ~$2800 SEL-2020, Inexpensive Media Transmission	**GOOD** $0 Protocol ~22,400 (8 SEL-2020) Inexpensive Media Transmission	**POOR** $28,000 Protocol (28 @ $1000), Expensive Media Transmission

SUMMARY

This document includes many of the reasons that we selected the star topology and designed the SEL-2020 and SEL-2030 Communications Processors. The star topology is more robust in that activities on one channel cannot harm the equipment or data transmitted on another channel. The topology is appropriate for point-to-point optical fiber channels.

Comparison of SEL-2020 Star Network to Shared Networks 970310