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# MANAGEMENT INFORMATION BASE MODULE FOR ELECTRICAL POWER SYSTEM CONFIGURATION AND USE[1]

**Summary**. Internet standards describe a virtual information store, termed the Management Information Base (MIB), which is made available through Simple Network Management Protocol (SNMP). No standard MIB exists to date for monitoring power lines in facilities over IP network. This paper defines a subset of the MIB for power system monitoring.

**Keywords**: Management Information Base, distributed database, information representation, electrical energy

# BAZA INFORMACJI ZARZĄDZANIA OPISUJĄCA KONFIGURACJĘ I WYKORZYSTANIE SYSTEMU ELEKTROENERGETYCZNEGO

**Streszczenie**. Standardy dotyczące Internetu opisują wirtualną bazę danych do zarządzania (MIB), dostępną za pośrednictwem protokołu SNMP. Nie istnieje aktualnie standardowy moduł MIB do monitorowania za pośrednictwem protokołu IP linii zasilających w budynkach czy poza nimi. Niniejszy artykuł definiuje zawartość MIB do monitorowania systemu energetycznego.

**Słowa kluczowe**: Baza informacji zarządzania (MIB), rozproszona baza danych, reprezentacja informacji, energia elektryczna

## 1. Introduction

Managing power transmission systems or large facilities like data centers or buildings requires detailed and current information about power network configuration and use. Each of

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these environments contains many devices which are able to autonomously power on or off, or to reconfigure the power connections. External, domain-specific systems, for example HVAC systems, electrical safety relays, or building automation equipment trigger changes in their domains but usually do not exchange full information, so central monitoring remains crucial [1, 2, 3]. Power resources are increasingly constrained and facilities are sometimes approaching operational capacity limits. Also the financial and ecological cost of energy requires to know how much power is used in operations, and how much more is available to work with.

Recent developments in microcontroller technology [4, 5, 6] make it for the first time financially feasible to employ large numbers of distributed, TCP/IP networked power monitoring units, where proprietary solutions or serial communication were previously used [3]. Simple Network Management Protocol (SNMP), being recommended to accompany TCP/IP stack implementations [7], seems to be a good candidate to aggregate the information from many different distribution points and to transmit it uniformly to a management center. It is especially appealing for complex systems with many power sources and supply points, and with dense network coverage, like office buildings [2], datacenter facilities [1], or even large computer systems, with many power rails at different voltage levels [16].

Information for managing the entities in a communications network, which SNMP is used to transmit, is stored in virtual database called Management Information Base (MIB). A complete collection of information available on a given type of networked entity is called MIB-module [8]. There are currently no standard MIB-modules related to power system configuration and load. Current work in progress in IETF does not address the representation of information pertaining to the power system configuration and usage, i.e. to the existing electrical connections and load flow. In [9] Power Consumption MIB is presented which aims at monitoring only the peak and minimal power consumption by IP network element. The main intended use of this MIB-module is when optimizing performance of routers, which are able to lower the operation clock frequency when the amount of traffic decreases. Another work in progress [10] describes Power State MIB which only enumerates device power status (standby, low power, etc.) and also describes Energy MIB which lacks voltage and current monitoring. Energy-aware Networks and Devices MIB [11], on the other hand, stresses the issue of grouping Power Monitors for reporting or searching when using multiport devices with power on Ethernet (PoE) technology. The most complete in its reporting of voltage, current, power and energy is the Power and Energy Monitoring MIB [12], but while employing parent-child relationship for monitoring, it neglects the issues of source-receiver relationship in providing power. Its main drawback is that it is overly extensive in many dimensions, and would be hard to implement on a tiny, memory-limited, microcontroller-based device.

These devices will remain performance-constrained and memory-limited due to cost impact at massive implementation. Simple sensors are also assumed: ones which only return instantaneous values of voltage or current.

The goal of this paper is to create and describe a MIB-module for representing power system configuration and usage at monitoring spots, instrumented by the managed devices. The MIB-module encompasses parameters which are vital to monitoring current facility configuration, not power quality. Therefore the MIB-module presented in this paper deals with direct current and alternating current and represents information on existing electrical connections, voltage levels applied, currents drawn, load flows and energy consumption. Any higher-level dependencies between monitored spots are left out to be modeled at the Network Management System architecture layer.

## 2. Power monitoring tiny MIB

### 2.1. Information presented

From the point of view of facility monitoring, it is crucial to

- monitor for power outages and disconnections at monitoring spots to maintain high uptime of the business-critical equipment,
- measure energy consumption for billing purposes,
- measure peak equipment power (energy consumption rate) for capacity planning.

The central issue to tackle with is power (energy consumption rate) metering and presentation. Power $p$ is simply described as multiplication of voltage and current:

$$p(t) = u(t) \cdot i(t). \tag{1}$$

With direct current, power may be produced from the above by taking instantaneous voltage and current values. For alternating current circuit the above produces complex power, which is defined as complex sum of real power and reactive power. Reactive power and power factor are often neglected at the facility monitoring level, thus real power remains the only component of interest. Only the real power is related to energy transmission. Real power may be easily calculated based on rms (Root Mean Square) voltage value and rms current value, which for sinusoidal signals, is simply:

$$U_{rms} = \frac{U_{\max}}{\sqrt{2}}, \quad I_{rms} = \frac{I_{\max}}{\sqrt{2}}. \tag{2}$$

For typical, distorted, i.e. non-sinusoidal signals (see Fig.1), rms values must be calculated in a more general way, as integrals over some period T:

$$U_{rms} = \sqrt{\frac{1}{T}\int_{t_0}^{t_0+T} u^2(t)dt}, \quad I_{rms} = \sqrt{\frac{1}{T}\int_{t_0}^{t_0+T} i^2(t)dt}. \tag{3}$$

For meaningful results the period T should be equal to the base period of the signal, or a multiple of the base period. For the voltage frequency of 50 Hz T should be at least 20 ms. Another solution is to filter out the distortions by applying digital signal processing. In both cases the metering device should accept a value for the period T. Therefore the MIB-module must provide for such functionality.

Energy transported over the period T is based on real power and described as

$$e(t) = \int_{0}^{t} p(t)dt. \tag{4}$$

As energy consumed is the integral of power over time, it must be considered that downtime of the monitoring device will result in incorrect metering of equipment energy consumption. There is no easy and general way to avoid this problem, but to make such case detectable, the device must additionally offer a time tick value which monotonically increases and eventually overflows. Overflow of this value between consecutive polls will be notified by Network Management System and it will indicate shorter interruptions of device work. Longer interruption must be detected by higher level architectural elements, through failed polls from the Network Management System.

To monitor power system connections it is sufficient to measure if voltage has been applied at the spot. Instantaneous voltage measurement may provide acceptable results for direct current circuits; it is insufficient for alternating current circuits where voltage oscillates and crosses zero. Voltage rms value over the period of time T may be used instead, as it is needed for calculating power anyway. Using the rms value defers lack of voltage detection by at most T, which is entirely acceptable for facility monitoring.

To monitor equipment use of the connection, it is sufficient to measure if the current flowing exceeds a limit. It is possible for a given equipment item not to power off completely, so some current may be allowed and still interpreted as power-off state. The limit default value is be 0, but the device should accept different limit values depending on the equipment monitored and the MIB-module must cater for it.

As one monitoring device may supervise many measurement spots, the MIB-module must provide for multiple sets of values for distinct spots. A noticeable example may be monitoring three-phase circuit.

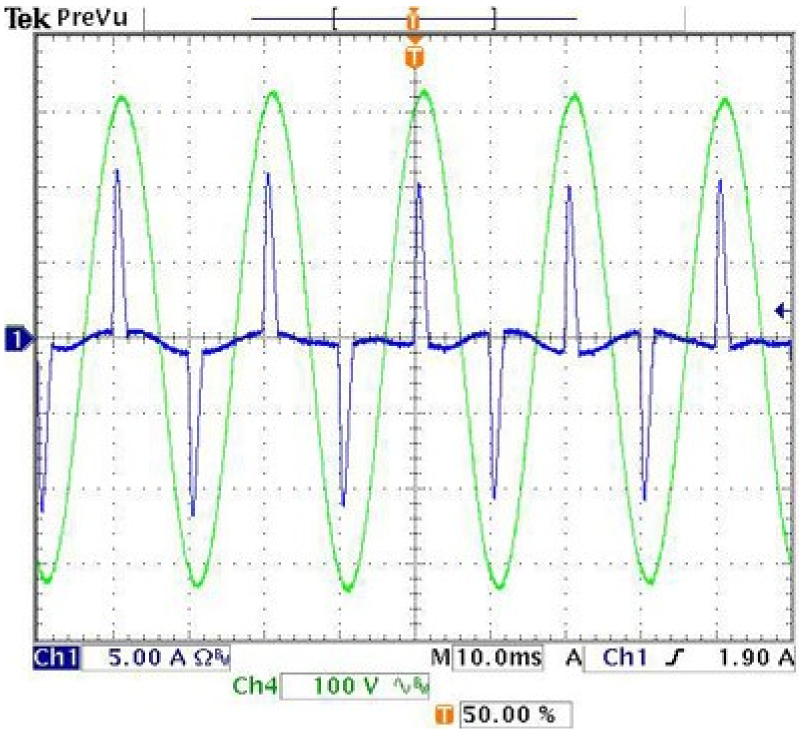


Fig. 1. Voltage (green line) and distorted current (blue line) of a switching power supply
Rys. 1. Napięcie (zielona linia) i zakłócony prąd (niebieska linia) zasilacza impulsowego

The device should also be able and empowered by MIB to send unsolicited messages on the following events:

- change in connection state (connected/unconnected),
- change in connection use (used/unused),
- exceeded limit of instantaneous power.

### 2.2. Power monitoring tiny MIB contents

A complete, formal MIB definition for SNMPv2 is accessible under [13]. The MIB tree is presented in Fig.2. The MIB name is *Power Monitorg Tiny MIB*. It contains 4 object groups: *powerValuesTable* for keeping measurement data, *measParamTable* for keeping measurement parameters, *notifEnableGroup* for enabling notifications and *notifGroup* which defines the notification types. The first two groups, *powerValuesTable* and *measParamTable,* represent tabular data contained in rows called *powerValuesEntry* ans *measParamsEntry*, respectively. The *powerValuesEntry* contains objects with scalar values storing the most recent measured values. The *measParamsEntry* contains objects with scalar values storing measurement period T and notification limits for current and power values.

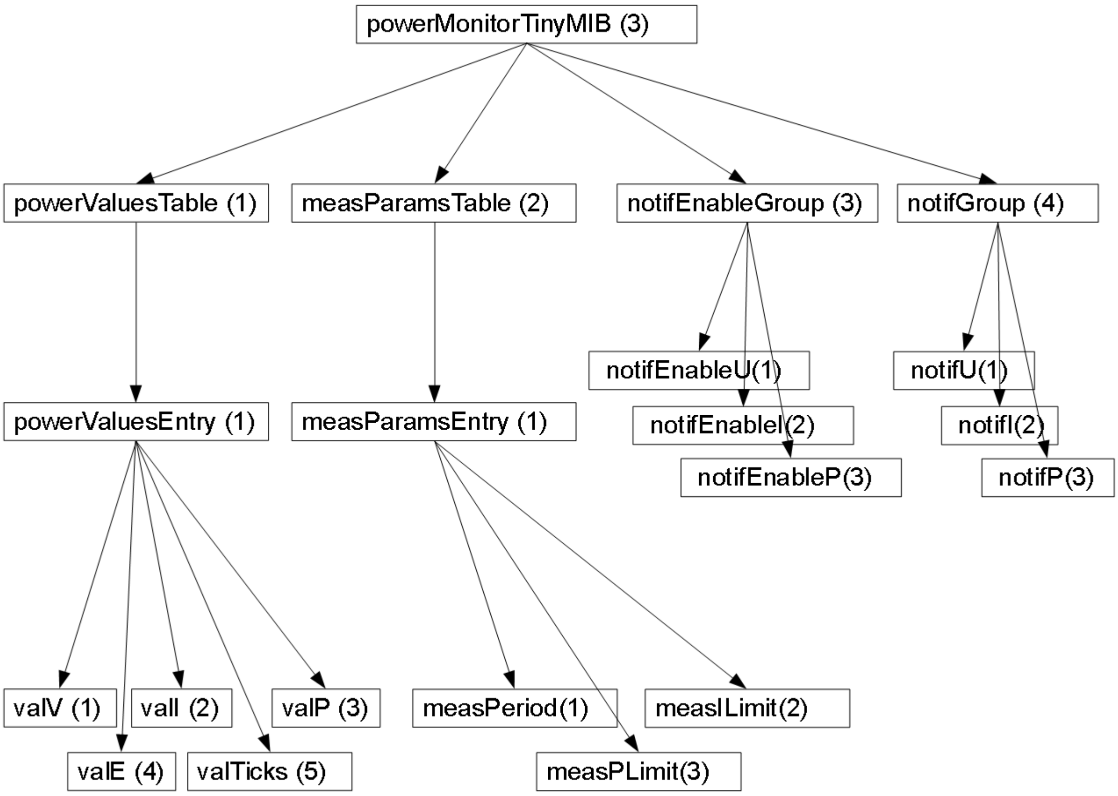


Fig. 2. MIB object dependencies and Object-Identifier (OID) tree
Rys. 2. Zależności między obiektami MIB oraz drzewo identyfikatorów OID

The example object characteristics of the *powerValuesTable* sub-tree in concise form is described below:

```
   powerValuesTable OBJECT-TYPE
       SYNTAX          SEQUENCE OF PowerEntry
       MAX-ACCESS      not-accessible
       STATUS          current
       DESCRIPTION
          "This table lists power monitoring spots"
       ::= { powerMonitorTinyMIB 1 }

   powerValuesEntry OBJECT-TYPE
       SYNTAX          PowerEntry
       MAX-ACCESS      not-accessible
       STATUS          current
       DESCRIPTION
          "An entry describes the power usage of a power spot."
  INDEX { valSpot  }
       ::= { powerValuesTable 1 }

PowerEntry ::= SEQUENCE {
           valSpot        Integer32,
           valV           Integer32,
           valI           Integer32,
           valP           Integer32,
           valE           Integer32,
           valTicks       Counter
}

   valSpot   OBJECT-TYPE
       SYNTAX          Integer32(0..10)
       MAX-ACCESS      read-write
```

```
            STATUS          current
            DESCRIPTION
               "This is the index - indicates the power spot where measurements
are taken"
            ::= { powerValuesEntry 6 }

        valV OBJECT-TYPE
            SYNTAX          Integer32
            UNITS           "volts"
            MAX-ACCESS      read-only
            STATUS          current
            DESCRIPTION
               "This object indicates the 'instantaneous' (i.e. over measurement
period T) rms voltage in volts"
            ::= { powerValuesEntry 1 }
```

## 3. Verification

To verify the MIB working an SNMP agent has been written on a PC witch Linux, using freeware Net-SNMP library [14]. Linux snmpget [15] command has been run repeatedly from a shell script to contact the agent and to get the values needed during testing. The MIB itself and the code used for verification is accessible under [13].

The simple SNMP agent written with Net-SNMP simulates just one spot with direct current, by assuming constant values for voltage U and current I. After getting the request, the agent calculates power P, and updates energy E based on time elapsed, returned by POSIX clock_gettime() with nanosecond resolution.

Three distinct tests have been run:

- Test A: both values for U and I set to zero, to simulate a disconnected spot.
- Test B: U set to 48, and I set to zero, to simulate a connected, but unused spot.
- Test C: U set to 48 and I set to 2, to simulate a spot which is connected and consuming energy.

Tests A and B were positive and resulted in returning the constant values, exactly as set in the agent. Test C was positive and resulted in returning constant power computed based on constant U and I, and returning growing amount of consumed energy, as depicted in Fig. 3. The values returned are not identical to the precomputed values as snmpget was run with a shell script, which did not guarantee exact timing.

## 4. Conclusions

A description of information in the form of Management Information Base has been worked out and presented in this paper. The MIB-module is designed for tiny, resource-constrained monitoring devices. It allows for storing and presenting information about the present configuration and use of the power lines and equipment connected to them. It provides information on:

- existing connections, and automatic notification of connection changes,
- existing connections use, and automatic notification of changes in use, for implicit equipment uptime monitoring,
- power drawn, and automatic notifications about exceeding a preset power limit, for capacity planning purposes,
- equipment energy consumption, for billing.

The MIB-module does not encompass power quality parameters nor does it deal with issues of battery power or contingency power. It is most useful for an energy meter at the facility or equipment level.

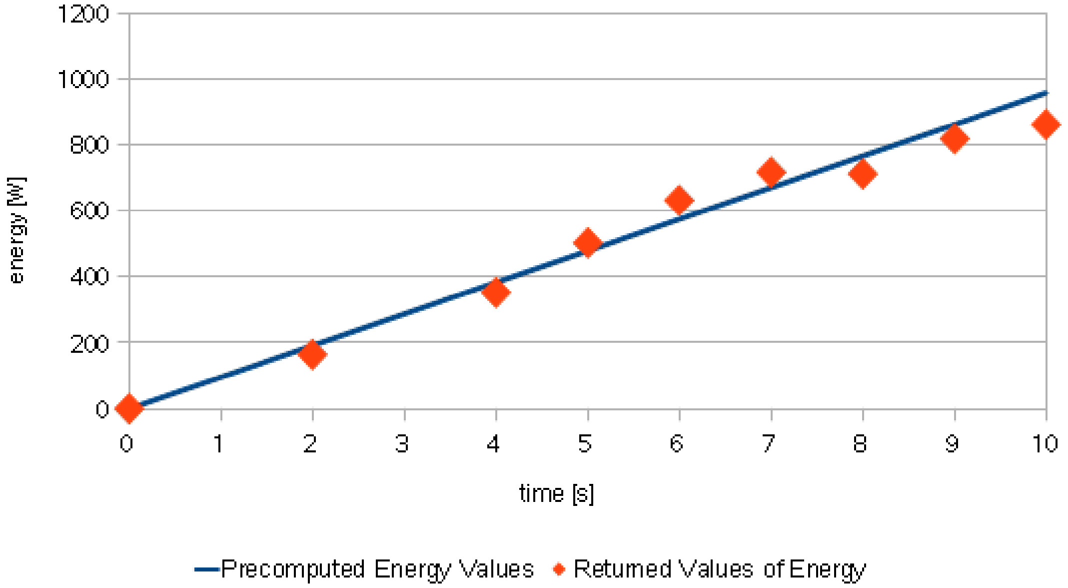


Fig. 3. Comparison of expected and returned values for Test C
Rys. 3. Porównanie wartości wyliczonych oraz wartości zwróconych przez agenta w teście C

Complementing with Network Management System is required for the MIB-module to provide polling, notification reception and the interpretation of information on a higher level, including for example the hierarchical influence of some power measurement spots on other, dependently connected monitoring spots.

The MIB-module role is to ensure a common monitoring and supervision over distributed and independent configuration mechanisms used in facilities. It may be additionally seen as an initial element for closing the control loop for facility automation, to provide automatic recovery from unplanned local failures in power provisioning.

Security of the information at the network level remains to be addressed separately.

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**Omówienie**

Monitorowanie systemu przesyłu energii elektrycznej czy dystrybucji energii elektrycznej w budynkach, wymaga dokładnej, bieżącej informacji o konfiguracji i wykorzystaniu linii zasilających. Istniejące systemy czy elementy są ze sobą nieskoordynowane. Automatyczne i ręczne przełączniki czy urządzenia zabezpieczające na liniach zasilających, powodują zmiany konfiguracji systemu. Z kolei załączenia i wyłączenia odbiorów energii dokonywane są ręcznie czy automatycznie na podstawie lokalnych decyzji.

Postępy technik mikroprocesorowych powodują, że opłacalne staje się rozmieszczenie dużej liczby drobnych czujników zarządzanych przez sieć IP z wykorzystaniem protokołu SNMP (*Simple Network Management Protocol*), wymagającego specyfikowania informacji do zarządzania w postaci MIB (*Management Information Base*). Brak dotąd standardu reprezentacji informacji do monitorowania systemu zasilającego w energię elektryczną. Również bieżące prace w komitetach standaryzacyjnych nie skupiają się na MIB dla drobnych urządzeń pomiarowych energii elektrycznej, wyposażonych w tylko podstawowe czujniki wartości chwilowych. Stąd niniejszy artykuł opisuje zakres takiego modułu MIB.

Istotna do rozważenia w systemach prądu przemiennego jest kwestia odkształceń realnych przebiegów (rys. 1), która narzuca konieczność wstępnego przetwarzania mierzonych wartości chwilowych przez całkowanie (3) lub filtrację cyfrową. Obie metody narzucają określenie dla urządzenia dodatkowego parametru (np. okresu przebiegu napięcia przy całkowaniu), który również należy przewidzieć w MIB.

Pomiar zużytej energii elektrycznej w celu obciążania odbiorców kosztami wymaga z kolei całkowania mocy w dłuższych okresach czasu (4). Rozważając działanie w długim czasie, należy przewidywać nieplanowane wyłączenia urządzenia pomiarowego, które prowadzą do zafałszowania pomiaru energii elektrycznej zużywanej tymczasem przez odbiory. Stąd przewidziano w MIB odczyt dodatkowej, stale rosnącej, wartości, aby wykrywać wyłączenia urządzenia pomiarowego krótsze niż odstępy między odczytami z centralnego systemu monitorującego NMS (*Network Monitoring System*).

Zaproponowany MIB nadaje się do monitorowania aktualnej konfiguracji (połączeń) linii zasilających oraz do pomiaru ich wykorzystania, w obwodach zarówno prądu stałego, jak i zmiennego, niezależnie od wartości napięcia i prądu oraz niezależnie od częstotliwości w przypadku prądu przemiennego. Przewidziano powiadamianie w przypadku zmiany stanu monitorowanego połączenia (przyłączenia lub odłączenia), w przypadku zmiany wykorzystania (włączenie lub wyłączenie odbioru) oraz w przypadku przekroczenia przewidzianej mocy czynnej.

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