A Maxim Integrated Products Brand

Energy Measurement in Split-Phase Systems Using 78M6612

APPLICATION NOTE

AN_6612_032

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Introduction

A split-phase electricity distribution system is a 3-wire single-phase distribution system, commonly used in North America for single-family residential and light commercial (up to about 100 kVA) applications. Its primary advantage is that it saves conductor material over a single ended single-phase system while only requiring single phase on the supply side of the distribution transformer. It is appropriate to call this power distribution system a 3-wire, single-phase, mid-point neutral system.

Distribution Transformer: a transformer supplying a 3-wire distribution system has a single-phase input (primary) winding. The output (secondary) winding is center-tapped and the center tap connected to neutral. This 3-wire system is common in countries with a standard phase-neutral voltage of 120 V. In this case, the transformer voltage is 120 V on either side of the center tap, giving 240 V between the two live conductors. See Figure 1.

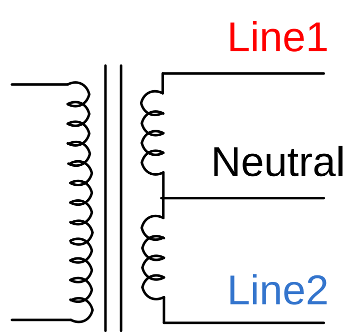


Figure 1: Distribution Transformer

In countries whose standard phase-to-neutral voltage is 120 V, lighting and small appliances are connected between a live wire (L1 or L2) and the neutral. Large appliances, such as cooking equipment, furnaces, water pumps, clothes dryers, and air conditioners are connected across the two live conductors and operate at 240 V, requiring less current and smaller conductors than would be needed if the appliances were designed for 120 V operations.

The voltages on the secondary of the transformer are:

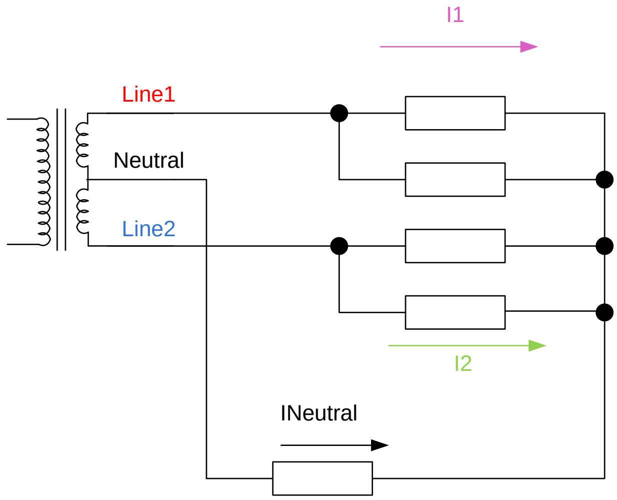
- Line1 to Neutral: 120VAC rms (230VAC rms / Europe)
- Line2 to Neutral: 120VAC rms (230VAC rms / Europe)
- Line1 to Line2: 240VAC rms (460VAC rms / Europe) or
- There is a 180° phase shift between Line1 (V1) and Line2 (V2)

Load Connection

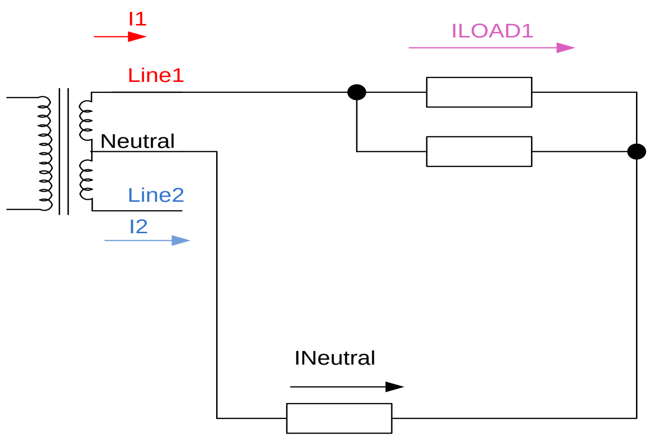
This section analyzes three different load cases. The load can be placed between:

1. Line1/Neutral + Line2/Neutral: balanced load (Case 1)
2. Line1/Neutral + No load on Line2: unbalanced load (Case 2)
3. Line1/Neutral + Line2/Neutral + Line1/Line2: unbalanced load (Case 3)

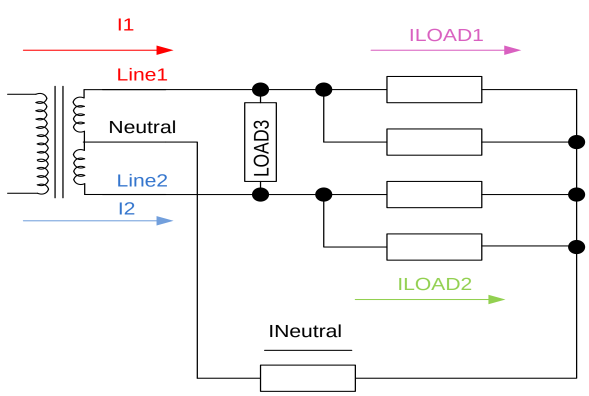
Case 1: The load is balanced and placed between the lines and neutral (I1 = I2), the current flowing in the shunt is equal to 0.



Case 2: The load is heavily unbalanced being on one phase only, the current flowing through the neutral is the same that is flowing in the load.



Case 3: This case is close to a real case application. There are loads of different values between each phase and neutral and there is a load (in general large appliance such as electric range or drier) between Line1 and Line2.

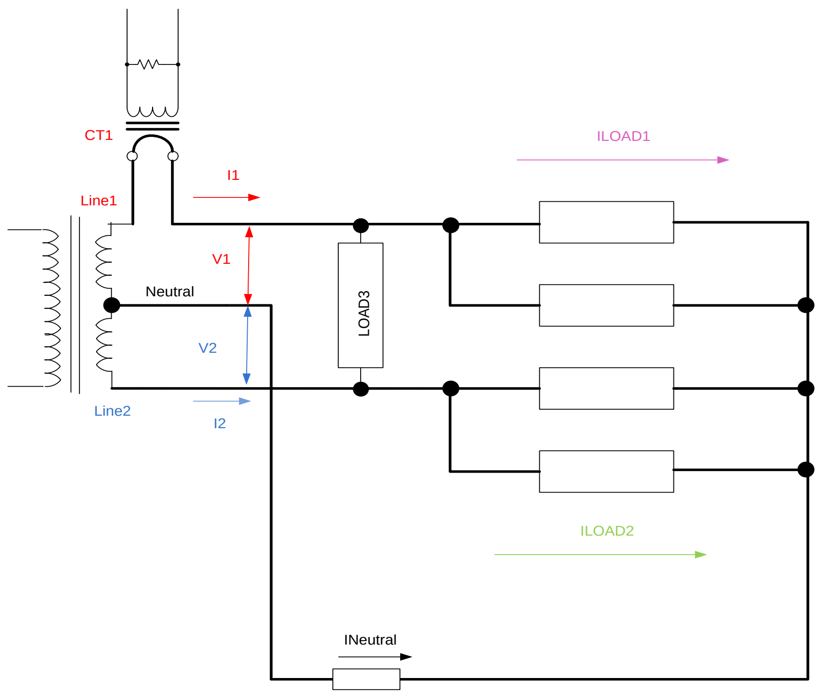


Measuring Power

The energy measurement subsystem requires measuring voltages and currents for both the V1 and V2. A single shunt would not be enough to derive the currents in the phases since there is a portion of the current, in Case 3 above which flows from Line1 to Line2 and not through the Neutral. Since the load most likely is not symmetrical, the current on both V1 and V2 outlet has to be considered.

Configuration 1:

This configuration utilizes a current transformer to sense the current on Line1, and a shunt to sense the current on the neutral.



The current on phase 2 can be computed as I2 = - (I1 + INeutral).

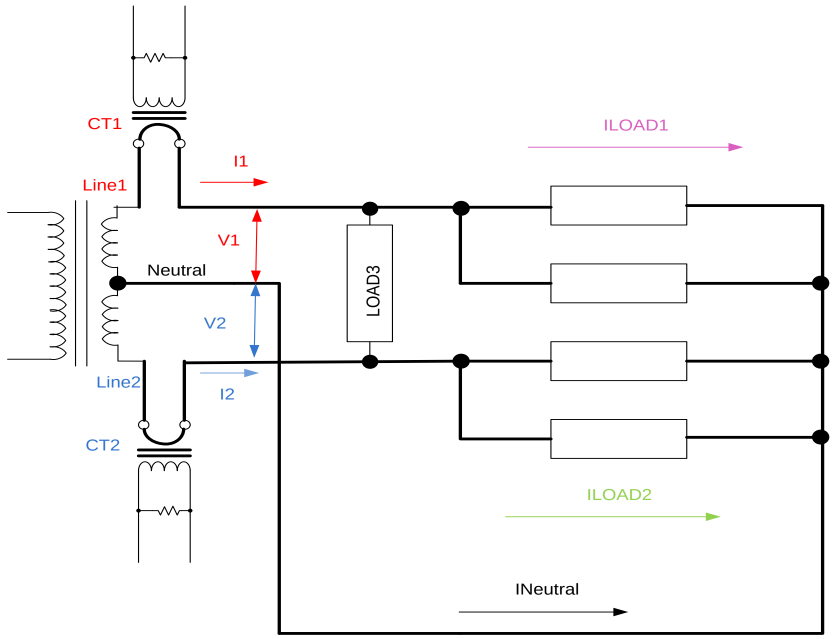
In order to reduce the number of input and components, it can be assumed that V1 = V2; therefore only one voltage input is needed and CE can use the data from one phase without heavy computation since this is simply 180 degrees shifted in phase.

This configuration requires either 3 inputs (2 currents + 1 voltage) or 4 inputs (2 currents + 2 voltages).

Configuration 2:

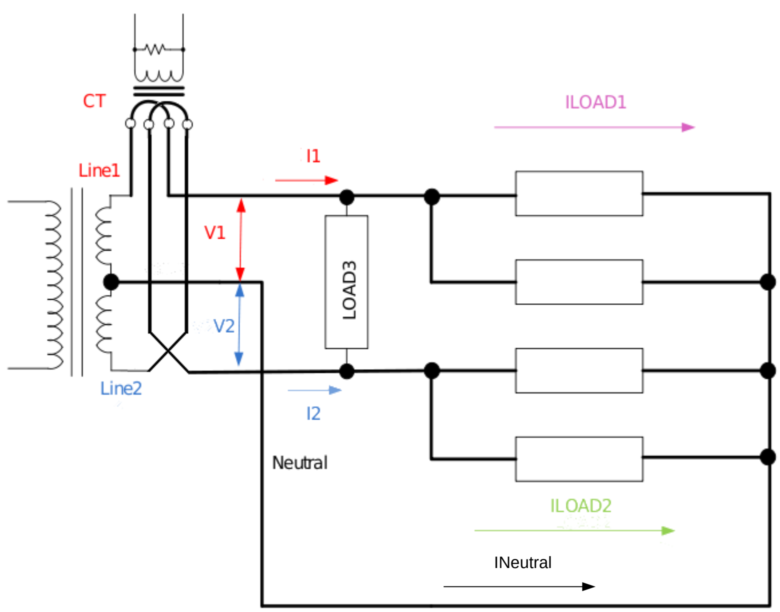
This configuration utilizes two current transformers to sense the current on Line1 and Line2; the shunt to sense current on Neutral is not needed.

In order to reduce the number of inputs and components, it can be assumed that V1 = V2; therefore only one voltage input is needed. Alternatively a second voltage divider connected to the remaining ADC differential input can be used to average voltages V1 and V2.



Configuration 3:

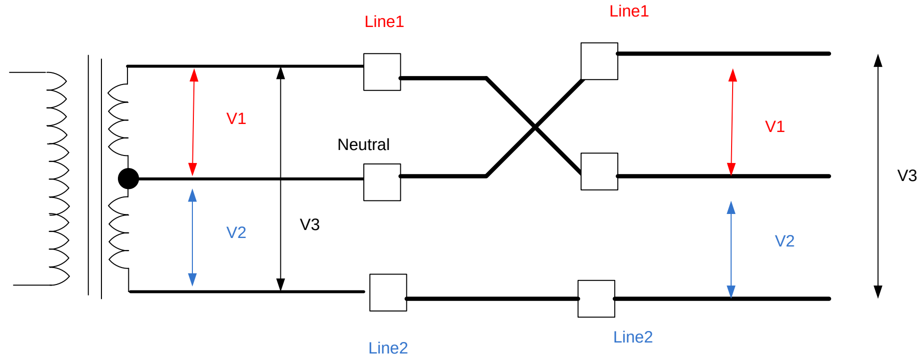
This configuration utilizes a single current transformer to sense the current on Line1 and Line2 and may likely be the lowest cost solution from a component count perspective. Voltage can be sensed as described in configuration 2. It is important to ensure that the current from both phases will "add" in the current transformer.



Additional Features

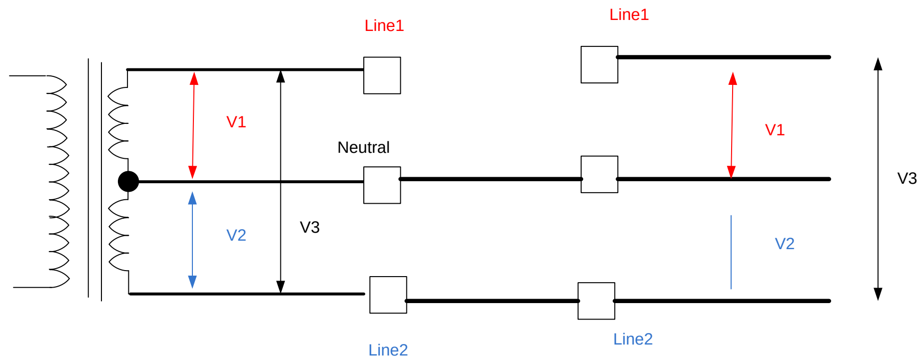
Additional features include wrong wiring detection, such as inversion between one of the lines and neutral and/or disconnect of one of the lines or neutral.

1. Neutral / line swapping detection.



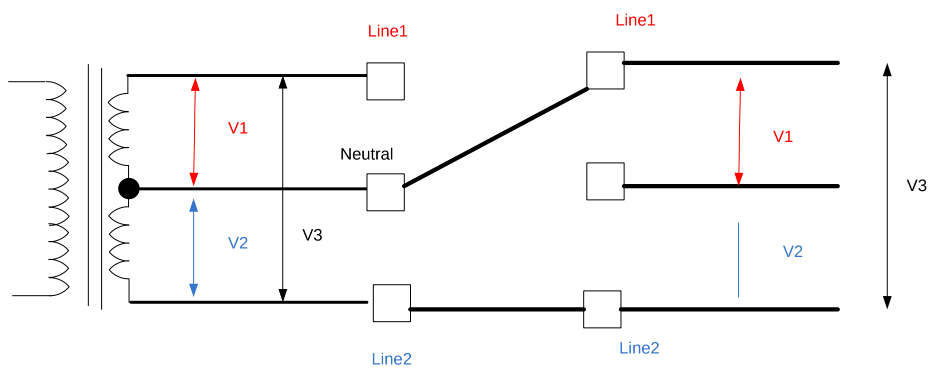
This condition is detected whenever V1 or V2 are significantly larger than V3.

2. Missing/disconnected line or neutral detection.



This condition is detected anytime V1 is significantly larger or smaller than V2.

3. Missing/disconnected line or neutral + swap detection



Multiple faults are detected using the criteria for line-swap and line-open. The criteria for setting this bit is V3rms<Vmax*2.

4. Sag and Dip Detection

Sag detection is provided on Line1 as part of the standard 78M6612 feature set.

Split-Phase Firmware

A firmware load for the 78M6612 was developed to implement split-phase measurement for two independent phases with a phase offset of 120° or 180°. It implements 4 channels (2I and 2V) and measures RMS for each channel as well as power for 2 phases. It requires 2 voltage dividers and 2 current transformers as sensors. Use the latest version of the file 6612_SPF_2CT_URT_Vx.xx.abs.

Data is provided via UART at 38400 baud using a Command Line Interface (CLI). After the first ">" symbol is received from the 78M6612, whenever a "." symbol is received, the 78M6612 has completed a conversion cycle and new data is available. Any characters sent to the 78M6612 are echoed back, so wait for a linefeed <LF> character before collecting data returned. Multiple commands can be sent on one line by placing spaces between them. Multiple results are received on the same line.

Result Registers

Registers can be read via the command line interface by sending a ")" symbol, followed by the register address (in hexadecimal), and a carriage return <CR> character. Data is returned in hexadecimal.

Example:)26 will read the RMS voltage for Line 2.

Address (hex)	Variable Name	Notes	Description
0	TEMP	Signed °C	Temperature delta from 25°C
1	FREQ	unsigned Hz	Line Frequency
2	STATUS	boolean	Alarms and other stati (see STATUS section)
6	VrmsA	unsigned mv	Line 1 RMS voltage
7	WattA	unsigned mva	Line 1 active power (W1)
26	VrmsB	unsigned mv	Line 2 RMS voltage (V2)
2A	IrmsA	unsigned ma	Line 1 RMS current (I2)
2B	VARA	unsigned mva	Line 1 reactive power
2C	VAsA	unsigned mva	Line 1 volt-amperes (Irms x Vrms)
2D	PFA	unsigned	Line 1 Power Factor (0 to 1.0)
46	Vrms3	unsigned mva	Line-to-line RMS voltage
47	WattB	unsigned mva	Line 2 active power (W2)
6A	IrmsB	unsigned ma	Line 2 RMS current
6B	VARB	unsigned mva	Line 2 reactive power
6C	VAsB	unsigned mva	Line 2 volt-amperes (Irms x Vrms)
6D	PFB	unsigned	Line 2 power factor (0 to 1.0)
80	WattT	unsigned mva	Total active power
93	IrmsT	unsigned ma	Total RMS current
94	VART	unsigned mva	Total reactive power
95	VAT	unsigned mva	Total volt-amperes

Input Registers

Registers can be written via the command line interface by sending a ")" symbol, followed by the register address (in hexadecimal), and equal sign "=", the value to be written (in hexadecimal), and a carriage return <CR> character.

Example:)A1=7 will set the Line 1 anti-creep threshold to 7 mV.

Address (hex)	**Variable Name**	**Units**	**Default**	**Description**
A0	VmaxA	mV rms	+471.500	Alarm limit for Line 1 rms voltage
A2	ImaxA	mA rms	+52.0	Alarm limit for Line 1 rms current
A4	ImaxB	mA rms	+52.0	Alarm limit for Line 2 rms current
D0	TempMin	°C	+0	Alarm limit for low temperature
D1	TempMax	°C	+70.0	Alarm limit for high temperature
D2	FreqMin	Hz	+59.0	Alarm limit for line frequency
D3	FreqMax	Hz	+61.0	Alarm limit for line frequency
D4	SagV	mV rms	+80.0	Alarm limit for Line 1 voltage sag
D6	Vpeak	mV rms	+140.0	Alarm limit for Line 1 peak voltage
D9	IpeakA	mA rms	+15.0	Alarm limit for Line 1 peak current
DC	PFminA		-0.70	Alarm limit for Line 1 lag
DD	PFmaxA		+0.70	Alarm limit for Line 1 lead
DF	IpeakB	mA rms	+15.0	Alarm limit for Line 2 peak current
E2	PFminB		-0.70	Alarm limit for Line 2 lag
E3	PFmaxB		+0.70	Alarm limit for Line 2 lead
E6	MASK	boolean (hex)	0x9E59FF	Mask for STATUS alarms (see STATUS Section)

STATUS Section (Alarm STATUS and MASK bits)

The following table lists the bits of the STATUS and MASK registers. The user sets MASK register to determine which bits will cause an ALARM, which is output on pin DIO20. Status bits clear automatically when the alarming condition no longer exists.

Bit	Name	Function
23	REV	Line-Neutral reversed
22-21		Reserved
20	MFault	Alarm for multi-fault event
19	ImaxT	Total current limit exceeded
18	PFmaxB	Line 2 power factor limit exceeded
17	PFminB	Line 2 power factor limit exceeded
16-15		Reserved
14	ImaxB	Line 2 rms current limit exceeded
13		Reserved
12	PFmaxA	Line 1 power factor limit exceeded
11	PFminA	Line 1 power factor limit exceeded
10-9		Reserved
8	ImaxA	Line 1 rms current limit exceeded
7		Reserved
6	LopenA	Line 2 open
5	LopenB	Line 1 open
4	VSag	Voltage sag event detected
3	Fmax	Line frequency limit exceeded
2	Fmin	Line frequency limit exceeded
1	Tmax	Temperature limit exceeded
0	Tmin	Temperature limit exceeded

Split-Phase Evaluation Board and Software

A Split-Phase Evaluation Board is available with a graphical interface to help users become familiar with the 78M6612 and the Split-Phase application. The demo displays RMS voltage and current, power, volt-amperes, and power factor for two independent phases as well as totals for these parameters. A true RMS line-to-line voltage is also shown. Indicators are provided for the various alarms as well.

Revision History

Revision	Date	Description
1.0	9/8/2010	First publication.