Nomenclatures:

Symbols	Abbreviations	Symbols	Abbreviations
3LNF	Three Line-to-Neutral Fault	Ki_{2c}	The disturbance indicator derived using the cross-correlation estimator (ri_{2c})
CT	Current Transformer	K_s	The selected setting of the time multiplier
CTR	Current Transformer Ratio	*MCSA*	Motor current signature analysis
CB	Circuit Breaker	N_c	The number of observations per one cycle for each current wave,
CMV	Common-Mode Voltage	N_s	The number of observations per the data set size ($N_s \leq N_c$) of the current wave,
DAC	Data Acquisition Card	*PMSMs*	Permanent magnet synchronous motors
DLF	Double Line Fault	*PWM*	Pulse Width Modulation
DLNF	Double Line-to-Neutral Fault	ri_{12a}	The strength of the cross-correlation estimator quantified between each two corresponding data sets for the two currents ($i_{1a}(n)$ and $i_{2a}(n)$) taken for '*A*' phase of the AC machine stator windings,
FFT	Fast Fourier Transform	ri_{12b}	The strength of the cross-correlation estimator quantified between each two corresponding data sets for the two currents ($i_{1b}(n)$ and $i_{2b}(n)$) taken for '*B*' phase of the AC machine stator windings,
$i_{1a}(n)$, $i_{1b}(n)$ and $i_{1c}(n)$:	The values of the three-phase currents at instant '*n*' measured at the three-phase supply end of the AC machine stator windings.	ri_{12c}	The strength of the cross-correlation estimator quantified between each two corresponding data sets for the two currents ($i_{1c}(n)$ and $i_{2c}(n)$) taken for '*C*' phase of the AC machine stator windings,
$i_{2a}(n)$, $i_{2b}(n)$ and $i_{2c}(n)$:	The quantities of the three-phase currents at instant '*n*' measured at the three-phase neutral end of the AC machine stator windings.	ri_{1a}	The strength of the auto-correlation estimator quantified between each two consecutive data sets that are shifted from each other by one cycle for the electrical current $i_{1a}(n)$ acquired at the supply side end,
$i_{1a}(n-N_c)$	The observation of the electrical current (i_{1a}) at the instant ($n-N_c$),	ri_{2a}	The strength of the auto-correlation estimator quantified between each two consecutive data sets that are shifted from each other by one cycle for the electrical current $i_{2a}(n)$ acquired at the neutral side end,
$i_{2a}(n-N_c)$	The observation of the electrical current (i_{2a}) at the instant ($n-N_c$),	ri_{1b}	The strength of the auto-correlation estimator quantified between each two consecutive data sets that are shifted from each other by one cycle for the electrical current $i_{1b}(n)$ acquired at the supply side end,
$i_{1b}(n-N_c)$	The observation of the electrical current (i_{1b}) at the instant ($n-N_c$),	ri_{2b}	The strength of the auto-correlation estimator quantified between each two consecutive data sets that are shifted from each other by one cycle for the electrical current $i_{2b}(n)$ acquired at the neutral side end,
$i_{2b}(n-N_c)$	The observation of the electrical current (i_{2b}) at the instant ($n-N_c$),	ri_{1c}	The strength of the auto-correlation estimator quantified between each two consecutive data sets that are shifted from each other by one cycle for the electrical current $i_{1c}(n)$ acquired at the supply side end,
$i_{1c}(n-N_c)$	The observation of the electrical current	ri_{2c}	The strength of the auto-correlation estimator quantified between each two consecutive data sets that are shifted from

	(i_{1c}) at the instant (n-N_c),		each other by one cycle for the electrical current $i_{2c}(n)$ acquired at the neutral side end,
$i_{2c}(n-N_c)$	The observation of the electrical current (i_{2c}) at the instant (n-N_c),	r_{auto}	The auto-correlation coefficient computed for each phase current
IM	Induction motor,	r_{pu}	The predetermined correlation pickup of the relay (it is $r_{pu} = 1.0 - \Delta s_2$ or $r_{pu} = 1.0 - \Delta s_3$),
Ki_{12a}	The disturbance indicator derived using the cross-correlation estimator (ri_{12a})	*SLNF*	Single-Line-to-Neutral Fault
Ki_{12b}	The disturbance indicator derived using the cross-correlation estimator (ri_{12b})	*TTTFs*	Turn-to-Turn Faults
Ki_{12c}	The disturbance indicator derived using the cross-correlation estimator (ri_{12c})	T_i	The estimated tripping time of the relay (in Sec)
Ki_{1a}	The disturbance indicator derived using the cross-correlation estimator (ri_{1a})	Ti_{1a}	The estimated tripping time (in Sec) of the relay based on the auto-correlation coefficient, $\boldsymbol{ri_{1a}}$
Ki_{1b}	The disturbance indicator derived using the cross-correlation estimator (ri_{1b})	Ti_{2a}	The estimated tripping time (in Sec) of the relay based on the auto-correlation coefficient, $\boldsymbol{ri_{2a}}$
Ki_{1c}	The disturbance indicator derived using the cross-correlation estimator (ri_{1c})	Ti_{12a}	The estimated tripping time (in Sec) of the relay based on the cross-correlation coefficient, $\boldsymbol{ri_{12a}}$
Ki_{2a}	The disturbance indicator derived using the cross-correlation estimator (ri_{2a})	Δs_1, Δs_2 and Δs_3	the numerical values of the correlation deviations,
Ki_{2b}	The disturbance indicator derived using the cross-correlation estimator (ri_{2b})	*DRPMSM*	Dual-Redundancy Permanent Magnet Synchronous Motor,
$T_{startup}$	The AC machine startup time	$I_{startup}$	The AC machine startup current,
T_{backup}	The tripping time of the main protection for the next protection zone (in the case of external fault).	ri_{1xy}	The cross-correlation estimator quantified between each two corresponding data sets for the two currents ($i_{1x}(n)$ and $i_{1y}(n)$) taken at the supply end for the two different phases '*X* and *Y*' of the AC machine stator windings,
ri_{2xy}	The cross-correlation estimator quantified between each two corresponding data sets for the two currents ($i_{2x}(n)$ and $i_{2y}(n)$) taken at the neutral end for the two different phases '*X* and *Y*' of the AC machine stator windings,		

Appendix 1: The specifications of the power model elements

The specifications of the power system elements	Numerical value
<u>Three-phase power supply:</u>	
Rated line voltage	*380 V*
Rated frequency	*50 Hz*
<u>Three-phase induction motor:</u>	
Rated power	*2.9 kW (Star connection)*
Rated line voltage	*400 V*
Nominal frequency	*50 Hz*
Rated line current	*6.3 A*
Rated speed	*1415 rpm*
No. of taps per each winding	*20 Tapes*
No. of turns per each tap	*5 Turns*
Turn dimension	*0.8* mm^2
<u>Current transformers (CTs):</u>	
Current Transformer turns' Ratio (CTR)	*200/5*
Frequency	*47…50…63 Hz*
CT accuracy class	*1.0*
Rated burden	*2.5 VA*
CT burden	*1* Ω
<u>Voltage Transformers (VTs)</u>	
Voltage Transformer turns' Ratio (VTR)	*220 / 6/ 3*
VT accuracy class	*0.5*
Nominal frequency	*50/60 Hz*
Rated burden	*25 VA*
<u>Miniature Circuit Breaker (MCB1)</u>	
Phase type	Three phase
Rated current	63 A
Rated voltage	400 V

Appendix 2: Input quantities of the proposed protection algorithm

Quantity designation	Quantity description	Value
$i_{1a}(n)$, $i_{1b}(n)$* and *$i_{1c}(n)$	The current measurements of *a*, *b* and *c* phases, respectively, at the instant *n* taken at the supply end of the AC machine stator windings,	They are measured on-line and updated
$I_{2a}(n)$, $i_{2b}(n)$* and *$i_{2c}(n)$	The current measurements of *a*, *b* and *c* phases, respectively, at the instant *n* taken at the neutral end of the AC machine stator windings,	
F_c	The fundamental cycle frequency for electrical signals	50 *Hz*
T_c	The cycle time interval	20 milliseconds
F_{sp}	The frequency rate of the digital system	2.5 *kHz*
T_{sp}	The sampling time span	0.4 milliseconds
N_c	The sample size per each one cycle, $N_c = T_c / T_{sp}$ or $N_c = F_{sp} / F_c$	50 samples/cycle
N_s	The sample size per each data set area, $N_s = N_c$	50 samples/data set
T_{ds}	The full display time	10 cycles
Δs_1	The predetermined deviation for the cross-correlation coefficients: (ri_{12a}, ri_{12b} and ri_{12c})	+0.05
Δs_2	The predetermined deviation for the auto-correlation coefficients: (ri_{1a}, ri_{1b} and ri_{1c})	+0.05
Δs_3	The predetermined deviation for the auto-correlation coefficients: (ri_{2a}, ri_{2b} and ri_{2c})	+0.05
K_s	The selected setting of the time multiplier used for estimating the tripping time in the case of TTTF,	0.3
r_{pu}	The predetermined correlation pickup of the relay (it is $r_{pu} = 1.0 - \Delta s_2$ or $r_{pu} = 1.0 - \Delta s_3$), and	+0.95